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In–Situ Biological Degradation Test at Kelly Air Force Base, Volume I: Site Characterization, Laboratory Studies and Treatment System Design and Installation

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In situ biological degradation involves stimulation of the indigenous subsurface microbial population, by the addition of nutrients and an oxygen source (hydrogen peroxide), in order to promote degradation of organic contaminants present in soils and groundwater. The site selected for the demonstration of *in situ* biodegradation contains a mixture of inorganic and organic contaminants including electroplating wastes, chlorinated solvents, cresols, and chlorobenzenes. The soils are classified as gravelly clay loams and the hydraulic conductivity within the demonstration site varies from 0.11 to 9.26 ft/day. The design of the field demonstration involved computer modeling using a two dimensional nonsteady state model to determine the number and placement of injection and extraction wells. Stabilized hydrogen peroxide and specially formulated nutrients are introduced to the subsurface and the groundwater is circulated by pumping and gravity injection. Routine monitoring of chemical and biological parameters has been conducted during a 3-month operation period from June through September 1985. These results are presented and indicate that rapid transport and

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19. breakthrough of ammonia and phosphate has occured in areas of high hydraulic conductivity. The microbial population has adapted to the addition of nutrients and incremental increases of hydrogen peroxide and remains viable. Comparisons of performance and cost are also presented against more traditional treatment approaches.

EXECUTIVE SUMMARY

This project is intended to demonstrate the applicability of *in situ* biological degradation for removal of organic contaminants from contaminated soils and groundwater. *In situ* biological degradation involves stimulation of the indigenous subsurface microbial population, by the addition of nutrients and an oxygen source (hydrogen peroxide), in order to promote degradation of organic contaminants present in soils and groundwater. This interim report covers background studies associated with this project, as well as the installation and early operation of the treatment system.

The site selected for the demonstration project contains a mixture of inorganic and organic contaminants. The soils are generally classified as gravelly clay loams, and hydraulic conductivities within the demonstration site vary over two orders of magnitude. This report provides information on cost, applicability, capabilities, and limitations of *in situ* biodegradation for a waste site of varied hydrogeologic conditions, which contains a diverse mixture of both inorganic and organic wastes.

Background investigations were performed prior to implementation of the treatment system and the results are presented in this report. These studies included determination of the site stratigraphy, permeability, and hydraulic conductivity. Enumeration of both soil and groundwater microbes was conducted to determine if an adequate population was present for successful biodegradation of the organic contaminants. A full inorganic and organic contaminant profile of the subsurface soils and groundwater was determined.

Routine monitoring of chemical and biological parameters has been conducted during the 3-month demonstration period from June through September 1985. These results are presented and indicate that rapid transport of nutrients has occurred in areas of high hydraulic conductivity. The microbial population has adapted to the addition of nutrients and incremental increases of hydrogen peroxide and remains viable. No conclusions have been reached to date on the degradation of organic contaminants at the site.

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PREFACE

This Report was prepared by Science Applications International Corporation, 8400 Westpark Drive, McLean, Virginia 22102, under U.S. Environmental Protection Agency (EPA) Contract 68-03-3113 for the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall Air Force Base, Florida, and the EPA Office of Research and Development, Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio. A number of subcontractors and consultants were used to provide specialized expertise for in situ biological degradation. These subcontractors and consultants include: FMC Corporation, Aquifer Remediation Systems: Dr. C.H. Ward, Rice University; Memphis State University; Mr. Paul Rogoshewski; K.W. Brown and Associates; Hamilton Drilling and Engineering Testing, Inc.; Environmental Research Group, Inc; Shilston Engineering Testing Laboratories; and Aqualab, Inc.

This report, Volume I, summarizes work done between May 1984 and September 1985. Volume II, summarizing the treatment process, will be published at a later date. Captain Edward Heyse was the AFESC Project Officer, while Mr Stephen James was the EPA Office of Research and Development Project Officer.

This report discusses laboratory testing and field demonstration, using various formulations of nutrients and hydrogen peroxide. It does not constitute an endorsement of these products by the Air Force or EPA, nor can it be used for advertising the product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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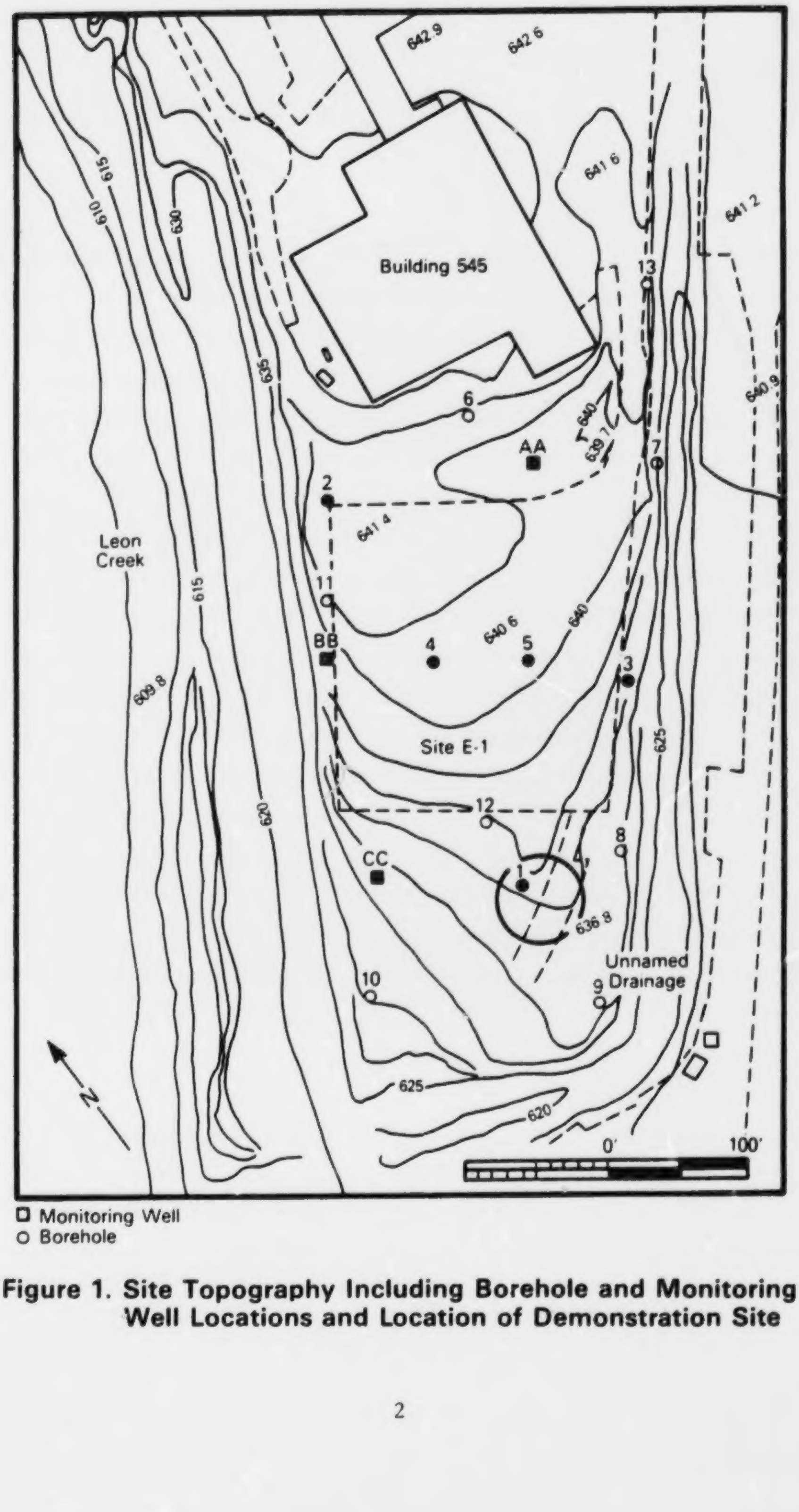
SECTION I

INTRODUCTION

The purpose of this project is to develop a system to demonstrate in situ biological degradation and its applicability to cleaning up hazardous waste sites and waste-contaminated soil and groundwater. The system that was developed is being field-tested on a hazardous waste site at Kelly AFB, San Antonio, Texas. In situ biological degradation has the potential for being more effective than other remedial technologies at comparable cost.

In situ biological degradation of contaminants in soil and groundwater involves stimulation of the indigenous subsurface microbial population in order to promote degradation of organic contaminants. This process utilizes aerobic degradation pathways and, therefore, requires that a source of oxygen be supplied to the subsurface environment. Previous work by others has shown that conventional aeration techniques cannot consistently supply an adequate amount of oxygen for in situ treatment and, thus, limit the amount of degradation that occurs. The field demonstration at Kelly AFB will help evaluate the effectiveness of using low levels of hydrogen peroxide as an oxygen source, which potentially could provide as much as 50 times the level of oxygen provided by conventional aeration. In addition to supplying oxygen to maintain the aerobic conditions, nutrients, such as nitrogen and phosphorus, are being added to enhance the growth of the microbial population.

The field demonstration was performed within a 60-foot diameter area located on the waste site identified as E-1 in the Installation Restoration Program (IRP) Phase I study at Kelly AFB. The site map is included as Figure 1 and indicates the location of the demonstration site within the shaded, circular area. Within this area, nine pumping wells and four gravity injection wells were placed to recirculate groundwater. As recirculation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609.8
625
Site E-1
620
12
8
CC
1
636.8
Unnamed Drainage
10
9
625
620
N
0'
100'
Monitoring Well
Borehole

Figure 1. Site Topography Including Borehole and Monitoring Well Locations and Location of Demonstration Site

takes place, a specially formulated nutrient solution and stabilized hydrogen peroxide are added to the flow before reintroduction to the subsurface to enhance the ability of the indigenous microbes to degrade contaminants.

This project to demonstrate feasibility and effectiveness of in situ biological degradation has included a feasibility study and a laboratory treatability study to evaluate potentially applicable in situ treatment options and to optimize their design. A demonstration-scale in situ treatment system was then installed, started up, and monitored at a Kelly Air Force Base waste site. Operation of the in situ treatment system has proceeded for only 3 months as this report was written (September 1985). Another 6 months to 1 year of operation may be needed to show significant degradation of wastes present. Continued operation of the system is planned.

The purpose of this report is to document progress of the demonstration. The body of the report includes discussions of site characterization in Section II, treatability studies in Section III, and the field demonstration in Section IV. Results gained to date are discussed in Section V. Conclusions that can be drawn from project activities to date and applicability and effectiveness of the technique are given in Section VI.

A. OVERVIEW OF IN SITU BIOLOGICAL DEGRADATION

In situ biological degradation is a technique which utilizes microbial degradation for treating zones of contamination in the subsurface environment. The basic concept involves altering environmental conditions to enhance microbial metabolism or cometabolism of organic contaminants, resulting in the breakdown and detoxification of those contaminants. In situ biological degradation involves stimulating the indigenous subsurface microbial populations to degrade the organic wastes "in place." To enhance biodegradation, it is necessary to provide elements which may limit bacterial growth and metabolism. Nonphotosynthetic microorganisms obtain energy for growth by oxidation of substrates in the presence of an electron acceptor, such as oxygen (Reference 1). Both oxygen and an organic substrate are required for aerobic microorganisms to obtain energy for all growth and maintenance. In addition, nutrients such as nitrogen, phosphate, and trace elements are required for cell growth. These elements must be present for *in situ* biological degradation to be effective as a treatment alternative.

There are many factors which affect the rate of biodegradation of organic compounds. These factors include temperature, pH, the number and species of microorganisms present, concentration of the substrate, presence of microbial toxicants and nutrients, and availability of electron acceptors (Reference 2).

Organic contaminants available in the subsurface can provide the carbon and energy source required for bacterial metabolism, and thus serve as primary substrates (Reference 3). However, the subsurface environment is generally characterized by low nutrient concentrations and limited availability of an electron acceptor required to support a microbial population for successful biodegradation.

Oxygen can be supplied to the subsurface to support aerobic respiration in the form of air, pure oxygen, hydrogen peroxide, or ozone. Hydrogen peroxide is being used as the oxygen source for this project and releases oxygen according to the following reaction: $2H_2O_2 \rightarrow O_2 + 2H_2O$. Hydrogen peroxide use has several advantages, compared to other sources, because greater concentrations of oxygen can be delivered to the subsurface, less equipment is required to oxygenate the subsurface, and biogrowth at the well can be minimized (Reference 4).

Nitrogen and phosphorus are the nutrients most frequently present in limited concentrations in soils. Other nutrients required for microbial metabolism include potassium, magnesium, calcium, sulfur, sodium, manganese, iron, and trace metals. Many of these nutrients may be present in the aquifer in sufficient quantities that additional supplements are not required (Reference 3).

The chemical form of nutrients may not be critical in terms of microbial requirements, depending on the site; however, other factors should be considered. For instance, nitrogen is typically supplied in the form of ammonia-nitrogen rather than nitrate-nitrogen. Ammonia is more easily assimilated by microorganisms and nitrate is considered a pollutant in drinking water in concentrations greater than 10 mg/l. Specific constitutents of nutrients may also present difficulties. Diammonium phosphate can result in excessive precipitation in the formation (Reference 5). Nutrient solutions containing sodium salts can cause dispersion of clays resulting in reduced permeability (Reference 3). High concentrations of calcium in the formation can form salts with phosphate,causing precipitation and loss of nutrient availability. Site geochemistry must be considered in determining the form and concentrations of nutrients added.

In general, organic contaminants present at selected sites may serve as primary substrates for microbial populations. Utilization of the organic compounds for cell growth and maintenance can result in successful site remediation if an adequate and adapted population of microbes exist in the subsurface environment. However, a sufficient supply of nutrients and an electron acceptor, namely oxygen, must be provided in order to maintain a healthy aerobic microbial population necessary for successful biodegradation.

B. TREATABILITY OF THE KELLY AFB SITE

1. Contaminant Treatability

In situ biodegradation has been most commonly employed to treat subsurface contamination by petroleum-based products. Compounds which have been documented as candidates for biological degradation include oily wastes such as crude oil tank bottoms, bunker C fuel oil, waxy raffinate wastes, high octane gasoline substances, and diesel fuel. In situ biodegradation was a technical outgrowth of landspreading technology. Exxon's Baytown refinery has been disposing of oily wastes by land farming since 1953 (Reference 6). Research in land farming has been performed by Shell Oil Company (Reference 7) and by Sun Ventures Inc. (Reference 8).

True in situ biodegradation began with the treatment of residual petroleum products in groundwater after no more free product could be recovered by pumping. Treatments consisted of supplying oxygen, by means of air sparging, and nutrients to the subsurface using injection/pumping well systems. In this manner, Sun Ventures remediated a spill of high octane gasoline in Ambler, Pennsylvania (Reference 9) and a gasoline leak in Millville, New Jersey (Reference 10). A similar technique was used for a gasoline and diesel fuel spill at La Grande, Oregon (Reference 11). The American Petroleum Institute is sponsoring a demonstration of in situ biodegradation at a gasoline-contaminated aquifer in Indiana, using hydrogen peroxide as an oxygen source (Reference 12). Other cases of biodegradation of gasoline-contaminated aquifers exist, a majority of which have been for private clientele and are not well publicized.

In situ biodegradation has been used to clean up subsurface environments contaminated with substances other than gasoline and petroleum-based compounds. Treatability studies conducted for other sites have indicated that the subsurface microflora could be stimulated to degrade methylene chloride, acetone, n-butyl alcohol, and dimethyl analine contaminants resulting from a leaking underground storage tank (Reference 13). In another case, mutant bacteria were used to enhance biodegradation of acrylonitrile, phenol, o-chlorophenol, ethylene glycol, propyl acetate, and dichlorobenzene (Reference 10). However, in this case, other processes, including aboveground biological treatment, air stripping, and carbon adsorption, were combined with in situ biological treatment to accomplish site remediation.

The Kelly AFB site contains a wide variety of organic and inorganic contaminants. Chromium sludges, electroplating wastes, chlorinated solvents, cresols, chlorobenzenes, and other chemical compounds have been disposed at the site. Results from the laboratory treatability studies conducted for the field demonstration at Kelly AFB indicated the potential for degrading various compounds using in situ biodegradation.

Results of the treatability studies indicated the lower molecular weight hydrocarbons (n-alkanes) can be aerobically degraded. Straight chain hydrocarbon concentrations, present at the site as a result of gasoline, diesel, and jet fuel contamination, were significantly decreased during the 100-day lab study. The laboratory study also indicated that aerobic degradation of chlorinated aromatics such as chlorobenzene and chlorinated aliphatics such as 1,1-dichloroethane, and 1,1-dichloroethene could be expected.

Chlorinated aliphatic compounds were degraded under anaerobic conditions in soil and groundwater microcosms. These compounds included tetrachloroethylene (PCE), trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA). Due to the difficulties that would be involved with establishing and maintaining anaerobic conditions on site, the primary concern for the field demonstration is for compounds amenable to aerobic biodegradation.

Metal ions such as antimony, chromium, lead, nickel, silver, thallium, and zinc were not present at the site at levels which would be toxic to the microbial population. Inorganic metal compounds are not amenable to in situ biological treatment and no reduction in concentrations are expected due to microbial degradation. However, mobilization of metals is a concern under oxidizing conditions, particularly in the presence of a strong oxidant such as peroxide.

2. Hydrogeologic Setting

Hydrogeologic conditions conducive to biodegradation exhibit a balance between sufficient flow rates for transporting nutrients, providing sufficient oxygen to microbes, and an adequate surface to support the microbial populations. A number of the properties of the subsurface formations of concern to the success of *in situ* biodegradation are: particle size, particle distribution (degree of homogeneity), and permeability. Fine particles (silts, clays, and fine sands) provide a larger surface area for microbial activity. This is significant because biodegradation probably occurs on surfaces in the aquifer material (Reference 14). An increase in the percent of fines, however, also increases dispersion, retardation, and sorption, which restrict the transport of nutrients and oxygen. Medium-to-coarse particles (medium-to-coarse sands and fine-to-coarse gravels) allow for a greater permeability which aids in the transport of nutrients and oxygen. Medium-to-coarse grains, however, provide a reduced surface area for microbial activity.

Particle distribution determines the degree of contaminant spreading and the effectiveness of delivery of nutrients and oxygen to indigenous microbes to enable the eventual degradation of contaminants. Homogeneous formations (i.e., formations in which particles are of approximately equal size and composition) are conducive to complete biodegradation without having pockets of contamination remaining in material of lower permeability. Inhomogeneous formations have variable permeabilities which allow channelization of groundwater flow which leaves pockets of undegraded contaminants.

The permeability of a formation is its ability to transmit fluid and is a property of the medium alone (i.e., it is independent of the fluid properties; Reference 15). High permeability formations are desirable for *in situ* biodegradation because they can support a recirculation system and have a greater potential for transmitting nutrients and oxygen to microbes.

Clayey materials tend to exhibit low permeability whereas sands and gravels exhibit higher values.

In situ bioreclamation is affected by several site hydraulic properties. These include hydraulic conductivity, saturated zone thickness, specific capacity (or storage coefficient), and annual recharge. The hydraulic conductivity (K) of the subsurface formation is akin to its permeability except that the hydraulic conductivity is also affected by groundwater characteristics (Reference 15). Hydraulic conductivity values greater than 10^{-4} cm/sec (0.28 ft/day) are required for forced recovery, gravity injection, and nutrient and oxygen transport to be effective.

Multiplying the saturated zone thickness of an aquifer by its hydraulic conductivity yields its transmissivity. Increasing the saturated zone thickness of an aquifer increases its potential rate for transmitting groundwater. A saturated zone thickness of at least 10 feet is desirable for circulating groundwater to sustain the fluctuations induced by pumping and injection.

The specific capacity (or storage coefficient in the case of confined aquifers) represents the potential storage volume of an aquifer. An adequate storage capacity is required to sustain the pumping and injection of groundwater. Wide fluctuations in water table elevations due to recharge from rainfall infiltration could destabilize the microbial environment, as well as the water balance established for groundwater circulation. Adequate storage capacity or good surface drainage is required to compensate for the effects of recharge on the circulating system.

Several problems encountered in the testing of in situ bioreclamation at Kelly Air Force Base can be traced to varying hydrogeological conditions that exist at the site in certain areas. These problems include: restricted pumping and injection rates, variable penetration of nutrients and oxygen into the formation, and water table fluctuations due to rainfall. Restricted pumping and injection rates (the total injection rate into four wells is less than 1.0 gallon per minute) can be attributed to low hydraulic conductivities of approximately 4 x 10^{-4} cm/sec (1.14 ft/day; see Table 1), and a saturated zone thickness of only 7-10 feet. The saturated formation is composed of fine sands, silts, and clays with some gravels, which are unevenly distributed. The site investigation, conducted prior to the start of the field demonstration, indicated that the saturated formation consists of interbedded lenses exhibiting variable permeabilities, which precludes an even distribution of nutrients and oxygen to microbes in the formation. Finally, the low storage capacity exhibited by the saturated formation magnifies the impact of rainfall recharge on the water balance which is crucial to recirculating the groundwater at the low flow rates.

The field demonstration study at Kelly AFB should, therefore, be viewed as a test of the varying hydrogeological requirements for conducting *in situ* biodegradation. Also, the Kelly AFB site is one of the first applications of stabilized hydrogen peroxide as an oxygen source to degrade mixed hazardous wastes. Although hydrogeologic conditions are not optimum and the site contains varied organic and inorganic waste materials, these conditions do not preclude the effectiveness of *in situ* biodegradation at the Kelly site. Despite low flow conditions and the presence of inorganic contaminants, the microbial population at the site continues to flourish. This demonstration project will provide a better understanding of the capabilities and limitations of *in situ* biodegradation. In addition, information on the cost effectiveness of this treatment alternative will be obtained from the demonstration project and comparisons can be made with other more conventional remedial alternatives.

TABLE 1. HYDRAULIC CONDUCTIVITY DETERMINED FROM SLUG TESTS

Well No.[3]	5/30/85 Static WL (ft BGS[1])	5/30/85 WL Elev (ft ASL[2])	Hydraulic Conductivity (ft/day)
P-1	21.12	617.41	0.55
P-2	21.42	616.72	0.11
P-3	21.36	617.31	0.65
P-4	21.23	617.41	1.78
P-5	21.30	617.38	1.82
P-6	20.97	617.57	1.50
P-7	20.68	617.40	1.72
P-8	20.11	617.31	9.26
P-9	20.68	617.30	7.84

[1] Below Ground Surface
[2] Above Sea Level
[3] Pumping Well

Note: See Figure 10 for site configuration.

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SECTION II

SITE CHARACTERIZATION

A. HISTORY OF THE SITE

The site selected for investigation and field demonstration of in situ treatment is located in the extreme southern portion of Kelly AFB, San Antonio, Texas. This site, shown in Figure 1 and designated E-1 during the IRP Phase I investigation, was first used for the disposal of chromium-containing electroplating wastes from about 1940 to 1955. The area was again used, from the early 1960s to the mid 1960s, as a chemical evaporation pit for waste solvents and other organic compounds. According to the Phase I report, the area was filled with gravel and other materials after it was used for electroplating waste disposal, and then it was lined with clay before deposition of organic wastes. No evidence of the fill or clay liner was found during the site characterization portion of this project. After this area ceased receiving wastes in 1966, it was covered with a very thin gravel layer and asphalt-paved. The area is currently a fenced storage area for metal stock.

The site is located on a peninsula-like land form, bounded on the west by Leon Creek, and on the east and south by an unnamed intermittent drainage ditch. The site is approximately 15 to 20 feet higher in elevation than this surface drainage.

B. FIELD INVESTIGATION

1. Site Characterization

Data on site characteristics were collected from soil borings, chemical, and microbial analysis of groundwater and soils, and hydrologic field tests. The location of soil borings (Boreholes 1-13) is shown in Figure 1. The first set of five soil borings (Boreholes 1-5) was conducted in June of 1984 to collect soil samples for the determination of contamination concentrations and microbial populations. Priority pollutant analysis was also conducted on groundwater samples taken from three preexisting monitoring wells (Monitoring Wells AA, BB, and CC). Based on chemical analyses and microbial enumeration of these samples, additional soil and groundwater samples of a higher volume were taken from specific locations in September of 1984 for use in laboratory microcosm studies. The second round of eight borings (Borehole 6-13) conducted in October of 1984 was carried out to more fully characterize the subsurface at the site. Locations of borings and monitoring wells are shown in Figure 1. Finally, hydrologic field testing was conducted in January of 1985 within the area chosen for the demonstration to determine the hydrogeologic characteristics of the saturated zone underlying the site. Raw data from site characterization activities are given in Appendices A and B.

2. Site Hydrogeology

In order to design the in situ bioreclamation system, a determination of the hydrogeologic characteristics of the site was required. Field hydrogeologic investigations were conducted for the determination of the distribution of the alluvial sediments underlying the site and of the physical properties of the saturated zone. Based on findings from subsurface investigations and hydrologic testing, the site materials were found to have low permeability and the transport of contaminants was predicted to be slow.

To characterize the subsurface at this site, the first five boreholes were drilled as deep as 30 feet below land surface and the second set of eight boreholes was drilled to 60 feet. The boreholes were drilled using hollow stem augers and samples were taken every 5 feet. Drilling logs for the first five boreholes are included in Appendix A.

Gow-type split spoon samplers were used for sampling the first set of boreholes and shelby tube samplers were used for the second set to speed up the sampling process. Each sample was described for color, texture, consistency, and moisture.

A composite cross section, which covers boreholes 7 through 10 is shown in Figure 2. Soil samples taken from this region indicate that the first 30 feet below land surface is very inhomogeneous. A collection of gravels and sands in a silt and clay matrix typifies the region. From 30 to 60 feet below land surface a composite of clay and marl is present which is not known to yield water to wells in the vicinity of Kelly AFB. The high degree of variability in the first 30 feet makes it impractical to correlate units from borehole to borehole, or to specify subsurface zones of higher permeability.

Water level data collected in January of 1985 from preexisting IRP Phase II monitoring wells, open boreholes, and test wells indicate that a saturated zone with a continuous groundwater surface underlies the site. Groundwater elevations were used to contour the surface of the saturated zone, as shown in Figure 3. The flow gradient is towards Leon Creek, which suggests a possible hydrologic connection between the saturated zone and the creek. Groundwater movement in the saturated zone, however, is at a slow rate due to the predominance of gravels and sands in a silt and clay matrix.

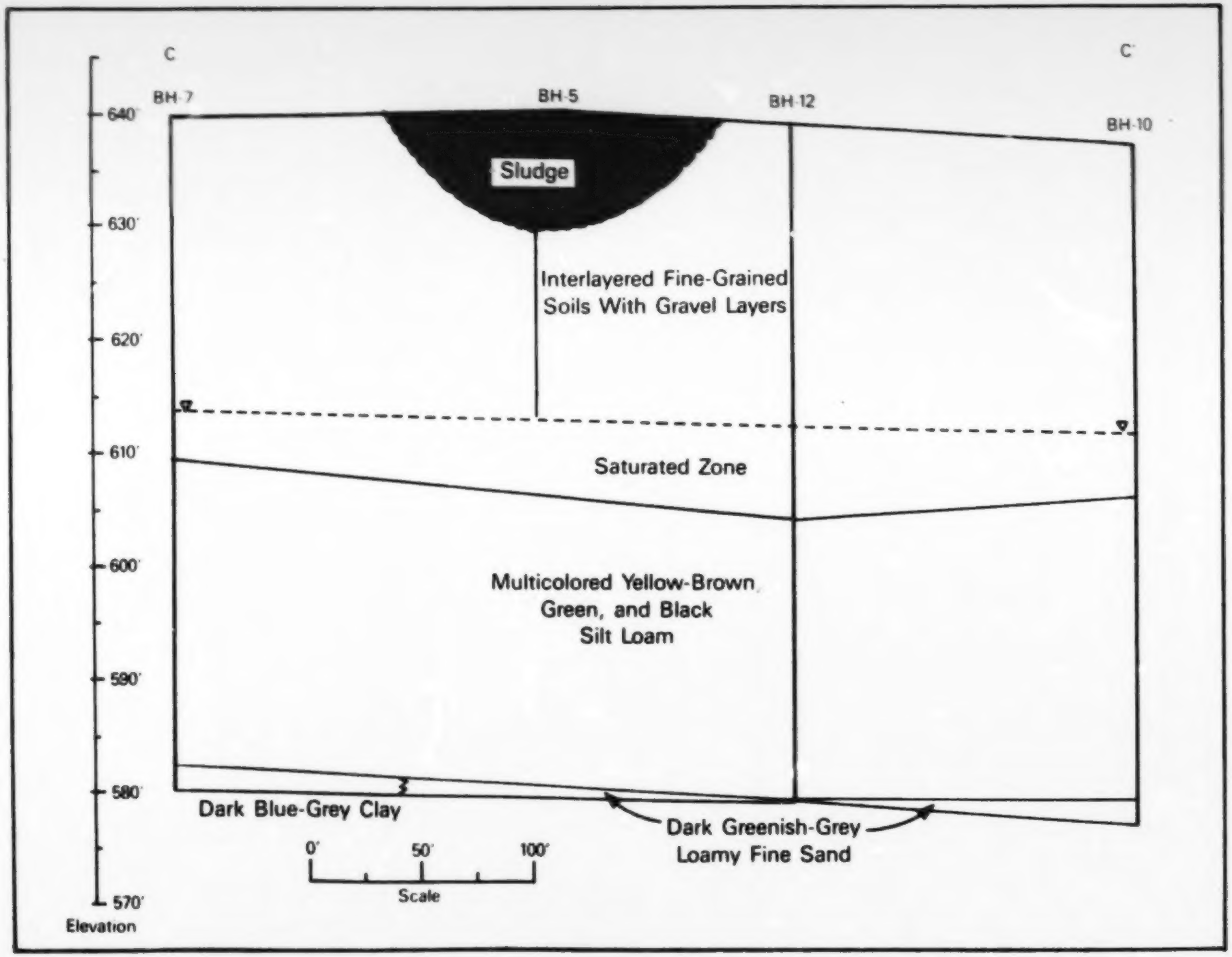
C
C'
BH-7
BH-5
BH-12
BH-10
640'
630'
620'
610'
600'
590'
580'
570'
Elevation
Sludge
Interlayered Fine-Grained
Soils With Gravel Layers
Saturated Zone
Multicolored Yellow-Brown
Green, and Black
Silt Loam
Dark Blue-Grey Clay
Dark Greenish-Grey
Loamy Fine Sand
0'
50'
100'
Scale

Figure 2. Composite Cross Section From BH-7 to BH-10

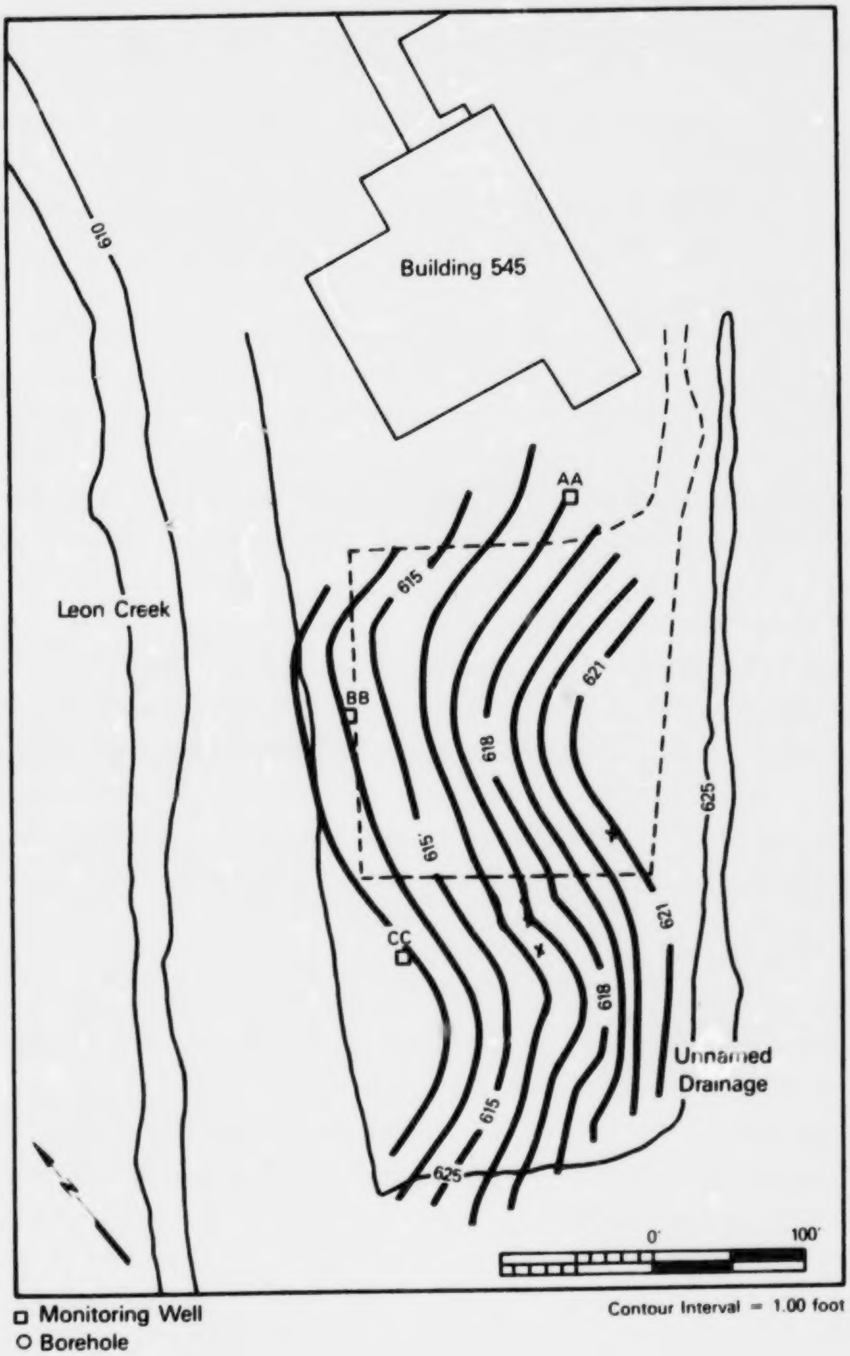
Building 545
610
Leon Creek
AA
BB
CC
615
615
615
618
618
621
621
625
625
Unnamed Drainage
0'
100'
Monitoring Well
Borehole
Contour Interval = 1.00 foot

Figure 3. Groundwater Surface Elevation Contours at the Kelly AFB Site

A test pumping well and two observation wells were installed in the vicinity of boreholes 1 and 12 in January 1985. A pumping test and two injection tests were performed. None of these tests caused any changes in water levels in the observation wells, but changes in water elevations in the pumping well were analyzed. These field tests yielded estimates of hydraulic conductivities of about 0.3 to 0.6 ft/day. Data concerning these tests are included in Appendix B.

Results of well pumping and injection tests indicate that the hydraulic conductivity of the saturated zone varied from 0.3 to 0.6 ft/day. This permeability restricted steady state pumping and injection rates during saturated zone testing to approximately 0.3 gallons per minute (gpm) in a 6-inch well. Rates exceeding 0.33 gpm dewatered the well in a pumping test and caused flooding in the well during the injection test.

Later investigations showed that the field tests were performed in an area of relatively low hydraulic conductivity. Test wells TP-01 and TO-02 became Wells I-1 and P-2,respectively. The hydraulic conductivities of all the pumping wells are given in Table 1. Wells P-8 and P-9 have hydraulic conductivities of 9.26 and 7.84 ft/day,respectively, more than an order of magnitude greater than in the area of the initial permeability testing. Hydraulic conductivities of the other wells ranged from 0.11 to 1.82 ft/day.

C. CONTAMINATION PROFILE

Comparison of the initial chemical analyses of soil samples with geological profiles indicates a correlation between site geology and vertical and horizontal migration of contaminants. Data are summarized in Table 2 and detailed in Appendix C. The depth of contamination together with borehole location provides an indication of the extent of contaminant migration. Two boreholes (Numbers 4 and 5) were located within the perimeter of the former evaporation pit. Consequently, samples taken at 5- and 9-foot depths in

TABLE 2. CONTAMINANT CONCENTRATIONS OF SOIL AND GROUNDWATER SAMPLES[e]

Borehole	Sample #	Depth ft.	Contaminants, ppm							Soil Description	Moist	Odor
			Purgeables	Volatiles[a]	Base/Neutral	Ketones	Benzenes & Chlorobenzenes	Hydrocarbons	Other			
1	1	7	0	0.02	0	0.037	0	0	0	gravelly silty clay	X	
	2	12	0	0.18	60	0	0	0	0	silty clay	X	
	3	18	0	0.14	46	0	0.005	221	45	sandy clay	X	X
2	1	13	0	0.045	60	0	0	0	2700[b]	silty clay loam	X	
	2	20	0	0.097	78	0.18	0	0	0	chert gravel		
	3	29	0	0.029	22	0.30	0.015	0	0	silt loam	X	X
3	1	10	0	0	78	0.25	0	0.009	0	silty clay, clay	XX	
	2	18	0	0.107	62	1.0	0	0	0	chert gravel		
	3	21	0	0	0	0	0	0	0	clay gravel, silt loam	X	
4	1	5	0	0.149	0.16	2.2	0.18	58	0	fine sludge	X	XX
	2	16	0	0.180	20	0	0	0	0	silty clay	X	X
	3	24	0	0.922	26	0.16	0	0.21	0	clay	X	X
5	1	9	0	0.402	56	25.8	116.2	878.8	11	fine sludge	X	XX
	2	16	0	1.294	20	0	0.52	0	0	sandy clay	X	X
	3	22	0	0.007	30	0.088	0.035	0	0	clay, mottled	X	X
Well	AA		8.6	0	<1	0	50	3595	170[d]	-----		X
	BB		0.9	91[c]	<1	0	0	0	0	-----		
	CC		23.9	0	<1	0	0	0	0	-----		

a. Primarily Phthalates, which may be artifacts, since present in soil blank.
b. 2-Propanol only.
c. Ethylbenzene only.
d. 1,1-dichlopentyl only.
e. **Soil and water sampled June 1984.**

located outside the perimeter of the former evaporation pit, and show low contaminant concentrations at all sampling depths. The low concentrations in these two boreholes suggest that horizontal migration is not significantly aided by the presence of gravels in the silty clay matrix at these locations.

High concentrations of hydrocarbons in a sample taken at an 18 foot depth near the demonstration area (Borehole 1), together with the absence of measurable hydrocarbons in samples taken at 7 to 12 feet, suggest that horizontal migration of contaminants has occurred from beneath the former evaporation pit. The lack of any vertical migration observed in the perimeter boreholes suggest that the contaminants detected at the 18-foot depth near the demonstration area migrated from a section underlying the former evaporation pit which has a higher vertical permeability. An average water level in this borehole of 614 feet ASL (measuered 10/19/84) and a past water level measurement of 616.3 feet ASL (measured 6/19/84) indicate that the depth from which the sample containing high hydrocarbons was taken potentially falls within a zone of fluctuating water table elevation. If it falls within this zone, contamination evident in this sample could have been transported from beneath the former evaporation pit by advection or dispersion in the saturated zone.

The results of the site characterization lead to consideration of how in situ biodegradation may apply to this site. Generally, the area chosen for the field demonstration contains the level and type of contaminants that appear to be treatable. Typical contaminants present are shown in Table 2. Higher concentrations of contaminants are not likely to be introduced into the treatment zone, as may have been the case if the treatment zone were directly beneath the asphalt pad. The low permeability found in this area has led to restriction of the treatment zone to a 60-foot diameter area within the saturated cross section.

D. MICROBIOLOGICAL CHARACTERIZATION

Preliminary laboratory studies were conducted to investigate the feasibility of in situ biodegradation at the Kelly site. Microbiological investigations were conducted to enumerate bacteria and determine if an adequate microbial population was present for biodegradation of the contaminants at the Kelly site.

Subsurface samples were collected from the initial set of five boreholes at three depths and direct and viable cell counts were performed. Acridine orange-direct counts were performed according to the method of Ghiorse and Balkwill (Reference 16). Estimates of viable bacteria density were made using dilution-spread procedures on seven media. Of these seven media, two were nutrient rich and two low-nutrient agars, with one of each amended with 1,4-dichlorobenzene. The other three agars were dilute groundwater agars from the three monitoring wells AA, BB, and CC. Figure 1 shows the locations of the five boreholes where soil samples were taken and the previously existing three wells installed in the IRP Phase II (well AA, BB, and CC) where groundwater samples were collected.

Acridine orange-direct cell counts ranged from 7.6 X 10^6 green fluorescent cells/wet gram to 1.68 X 10^8 cells/wet gram. Most core samples yielded counts between 1.6 X 10^7 to 4.3 X 10^7 cells/wet gram of sample. Viable cell counts ranged from 1.0 X 10^2 to 7.1 X 10^6 colony forming units/wet gram sample. All media yielded similar numbers of cells for any one sample. Also, there was little variation noted as a function of either site location, sample depth, or pollutant concentration. Complete data is contained in Appendix C.

Results of the preliminary microbial analyses indicated a substantial microbial population (10^7 to 10^8 organisms/gram soil) exists in the subsurface which will facilitate the biodegradation process. Viable cell counts on seven different growth media indicated a diverse or highly adaptive population capable of metabolizing a large variety of substrates. It was concluded from the microbiological investigation that a healthy population of microbes was present at the Kelly site and the limiting factor to successful site remediation would not be microbiological.

SECTION III

TREATABILITY STUDIES

Treatability studies were conducted to determine if biodegradation would occur at the site, quantify permeability of subsurface materials, and determine nutrient and peroxide stability in the presence of site soils and groundwater.

A. BIODEGRADATION STUDY

A laboratory treatability study was conducted with soil and groundwater from the Kelly site to determine if biodegradation of the organic contaminants present would occur. Other objectives of the study were to determine if toxic intermediate transformation products of biodegradation would be produced which may inhibit microbial growth and to determine if compounds resulting from oxidation/reductions reactions with hydrogen peroxide would be formed. The following microcosms were prepared with soil and groundwater from the Kelly site:

- Aerobic: stabilized H_2O_2 (Restore® 105) + nutrients
- Sterile aerobic control: stabilized H_2O_2 + nutrients
- Aerobic: O_2 + nutrients
- Anaerobic: amended with nutrients
- Sterile anaerobic control: amended with nutrients.

All raw data is included in Appendix D. In addition, a quality assurance/quality control plan was followed for all chemical analyses performed on microcosm samples, and is included in Appendix E.

1. Experimental Design

Soil samples were collected from 4 borings adjacent to Borehole 1, one boring adjacent to Borehole 4 and one boring adjacent to Borehole 5. Soil was packaged for shipment under a nitrogen atmosphere to protect any anaerobic organisms from oxygen toxicity. Samples were shipped in the dark at 4°C to prevent microbial activity. Groundwater samples were obtained, 4 gallons from Well AA, 1/2 gallon from Well BB, and 1 gallon from Well CC. Water samples were also shipped and stored in the dark at 4°C.

Soil cores were split longitudinally under nitrogen in a glove bag and all samples were divided into two lots, one for aerobic microcosms and the other for the anaerobic microcosms. Soil samples for the aerobic and anaerobic microcosms were handled similarly, except that all preparations for anaerobic microcosms were performed under nitrogen in a glove bag. Preparations for aerobic microcosms were performed in a glove bag inflated with air. Soil was homogenized to provide all microcosms with the same substrate profile and bacterial population.

Aerobic biodegradation testing was performed using both pure oxygen and hydrogen peroxide as oxygen sources. Sterilized controls for both aerobic treatments could not be performed due to the limited quantity of soil and groundwater available. Sterilized H_2O_2 treatment controls were performed since H_2O_2 treatment was more likely to produce chemical changes in the microcosms.

Microcosm size was dictated by the GC/MS sampling size requirements. Each aerobic microcosm consisted of a 200 ml, 10 percent soil/groundwater slurry in a 240 ml, amber, narrow-mouth bottle, capped with Teflon/silicon-lined septa screw caps. The headspace was minimized to prevent loss of volatiles. All treatments were ammended with nutrient media.

Hydrogen peroxide treatment microcosms received stabilized H_2O_2 (Restore 105®) injected through the septa. It was calculated that 300 ppm H_2O_2 would be required to degrade the 50 ppm hydrocarbons present in each microcosm. To avoid addition of toxic concentrations, only 100 ppm H_2O_2 was added to each replicate at any given time. Microcosms were dosed with 100 ppm H_2O_2 initially, and on day 20 and day 40. Microcosms receiving oxygen treatment were blanketed with 100 percent oxygen in the 40 ml headspace prior to capping. Microcosms were amended with additional 100 percent O_2, injected through the septa, on days 20 and 40.

Anaerobic microcosms were constructed similarly to the aerobic microcosms, but with the following exceptions. Microcosms were filled to the top with the soil/groundwater slurry, and capped with solid teflon/silicon-lined caps. Anaerobic microcosms were amended with a standard nutrient media which contained sodium sulfide as a reducing agent. To enhance anaerobic degradation, 500 mg/l of acetate was provided as a primary substrate. Controls were sterilized by gamma-irradiating intact microcosms with a cobalt 60 source for 1 hour.

All aerobic microcosms were incubated at room temperature (19-22°C) and were agitated by hand to enhance aeration, once a day up to Day 50. The Day 100 aerobic microcosms were subjected to continuous, shaker-table agitation from Day 50 until sacrifice. All anaerobic systems were also incubated at room temperature but were left undisturbed until sacrifice, to minimize the opportunity for ambient air to leak through the microcosm cap, compromising anaerobicity, and, in the event of cap leakage, to maintain the most reduced conditions possible at the bottom of these bottles.

Triplicate aerobic samples were then sacrificed after 1, 24, 49, and 100 days, while triplicate anerobic samples were sacrificed after 1, 25, 50, and 101 days, following preparation. At the time of sacrifice, the samples were subjected to volatile organic hydrocarbon analyses, extraction, and subsequent analysis by flame ionization detector-gas chromatography (FID-GC), electron capture detector-gas chromatography (ECD-GC) or gas chromatography-mass spectrometry (GC/MS). Briefly, at the time of sacrifice, each microcosm was agitated to ensure homogeneity and an aliquot was removed for volatile organic hydrocarbon analysis by GC/MS. A 1-ml aliquot of slurry was used to conduct simple spread plating to determine if viable populations were present in the microcosms. The remaining sample was centrifuged and the aqueous phase was decanted and processed at pH 12 and 2 for separate analyses of extractable hydrocarbons by FID-GC and GC/MS. In addition, unextracted aqueous samples were examined for pH, dissolved oxygen, and oxidation-reduction potential. The remaining soil was removed and processed for analysis of extractable priority pollutants and aliphatic and aromatic hydrocarbons by FID-GC and GC/MS, and analysis of intermediate and higher molecular weight chlorinated hydrocarbons, such as PCBs and pesticides, by ECD-GC. Triplicate samples were sacrificed for each of the five microcosm types. Each sample was analyzed and raw data from the triplicate analyses are presented in Appendix D. In addition, mean values and coefficients of variation (CV) are given in Appendix D. Additional details on the laboratory analysis procedures and quality assurance and quality control followed in the SAIC/La Jolla laboratories are presented in the QA/QC document for this program (Appendix E).

With regard to the analysis of the volatile organic hydrocarbon components by GC/MS, it should also be added that the components were present in an extremely wide (three-order-of-magnitude) dynamic concentration range which caused "carry-over" and saturation problems with the electron multiplier on the GC/MS system. Therefore, a number of samples had to be serially diluted and rerun on several occasions. A system blank was required between each sample run to demonstrate the lack of sample carry-over before additional samples were analyzed. Concentrated samples were desired in order to detect components present at the nanogram per gram (ppb) level such as trichloroethylene, tetrachloroethylene, trans-1,2-dichloroethene, 1,1,1-trichloroethane, and other lower molecular weight halogenated organics, including one halogenated aromatic compound, chlorobenzene.

2. Results and Conclusions

Over the 100-day course of the experiment, samples were sacrificed and analyzed for petroleum hydrocarbon contamination. System reagent blanks were obtained by sacrifice and analyses of empty containers at Day 1, 25, 50, and 100.

The Day 1 sample from a hydrogen peroxide amended microcosm was characterized by lower and intermediate molecular weight n-alkanes and an unresolved complex mixture between nC-18 and nC-25. With time, from Day 24 through 49 and 100, degradation of the straight chain, n-alkanes was apparent, and ultimately the predominance of the isoprenoid components, pristane, phytane, and pharnasane, was observed in the chromatographic profile. With continued microbial degradation, the unresolved complex mixture became a much more significant portion of the chromatograms compared to the resolved, straight chain, n-alkane components. Resolved hydrocarbons appear on the chromatograms as distinct peaks which can be assigned a specific retention time, while unresolved hydrocarbons are those groups of hydrocarbon compounds which cannot be defined as separate, sharp peaks. However, integration of the unresolved mixture of hydrocarbons can be accomplished to determine a total concentration of hydrocarbon compounds.

The chromatograms from the aerobic sterilized control samples indicate very little n-alkane degradation during the first 50 days of the experiment. At that time, a decrease in the resolved, n-alkane components was observed. The decrease in lower and intermediate molecular weight hydrocarbon concentrations may have been caused by abiotic chemical decomposition initiated by the peroxide present in the microcosm. Further evidence of no hydrocarbon degradation in the sterilized controls in the first 50 days is shown in Figure 4 where the time-series change in the ratio of the unresolved complex mixture to total resolved hydrocarbons is presented graphically. The increases in the peroxide treated microcosm and the oxygen supplemented system in this figure were significantly greater than those of the anaerobic

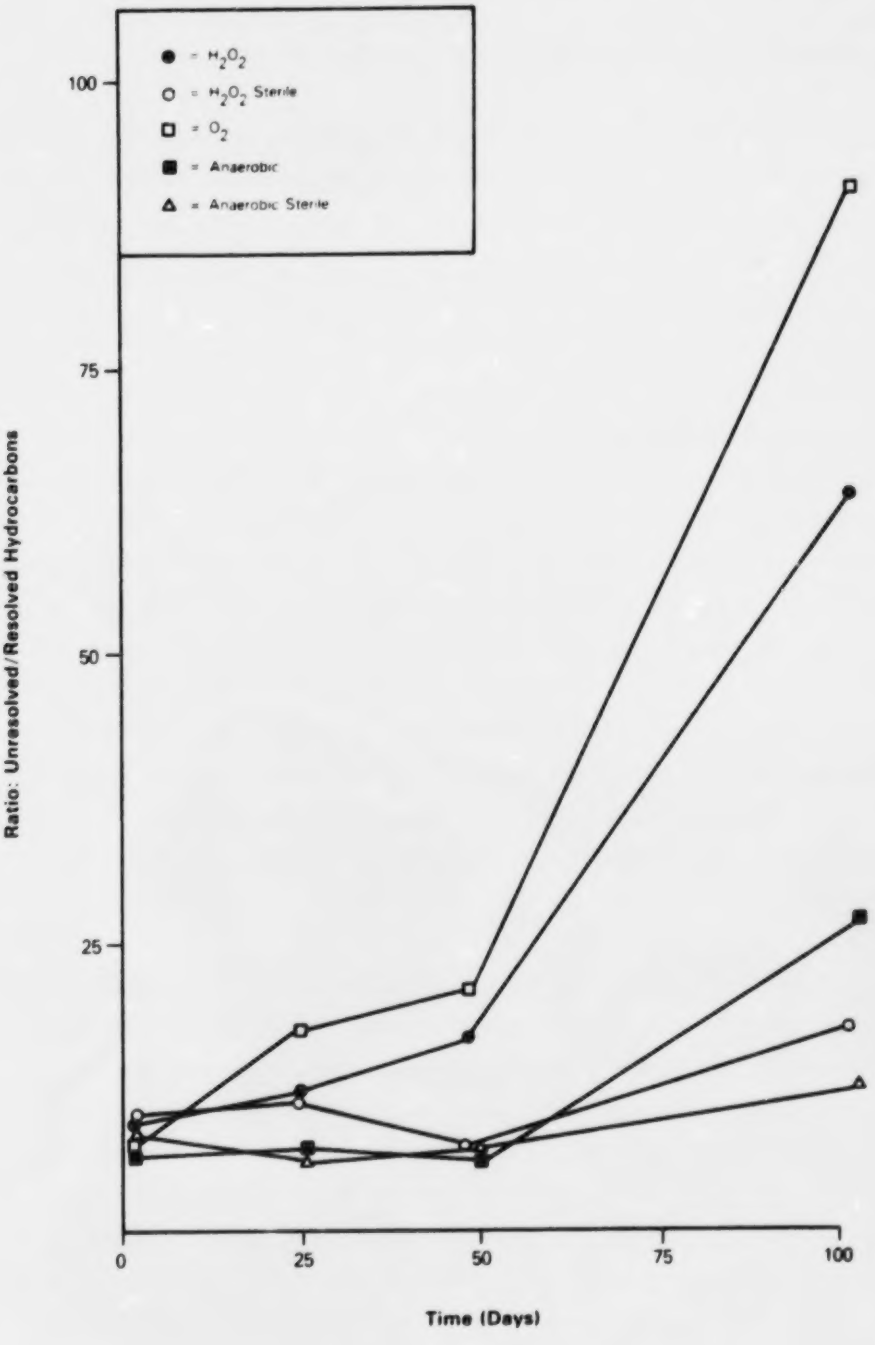

Figure 4. Ratio Unresolved/Resolved Hydrocarbons Versus Time

system, its sterile control, or the sterile counterpart of the hydrogen peroxide treated system. The ratio of the unresolved to resolved components for the anaerobic systems and the sterilized control remained between 5 and 20 for the 100-Day period, whereas the oxygen treated microcosm increased to a value equal to 91 and the peroxide supplemented microcosm increased to a ratio equal to 64.

In the oxygen treated microcosm, as in the peroxide treated system, significant amounts of resolvable n-alkanes were removed from the soil extracts over the 100-day period. Chromatographic profiles from both the anaerobic microcosms and the anaerobic sterile control microcosms show that very similar n-alkane profiles were observed with little or no evidence of any degradation of oil components.

Additional evidence of selected microbial degradation under aerobic conditions can be observed in Figure 5 which shows significant degradation of n-alkanes in the peroxide and oxygen treated microcosms. In contrast, the sum of the n-alkanes versus time remained relatively constant for the anaerobic sterile and nonsterile microcosms. Continued degradation in the peroxide treated sterile control may reflect an air leak or abiotic chemical degradation of the aliphatic hydrocarbons present.

In summary, from the chromatographic profiles and data presented on hydrocarbon components, it is evident that microbial degradation of hydrocarbon compounds occurred in the peroxide treated and oxygen amended microcosms. These compounds include the aliphatic, aromatic, and polar, hydrocarbon fractions. The sterile control for the peroxide amended microcosms showed relatively less degradation than its peroxide treated counterpart. However, there is a possibility that limited abiotic degradation of the aliphatic compounds occurred over time due to the peroxide present. The anaerobic microcosms and sterile controls showed essentially no significant aliphatic hydrocarbon degradation over the 100-day period. The change in appearance of the chromatographic profiles as the experiment proceeded also

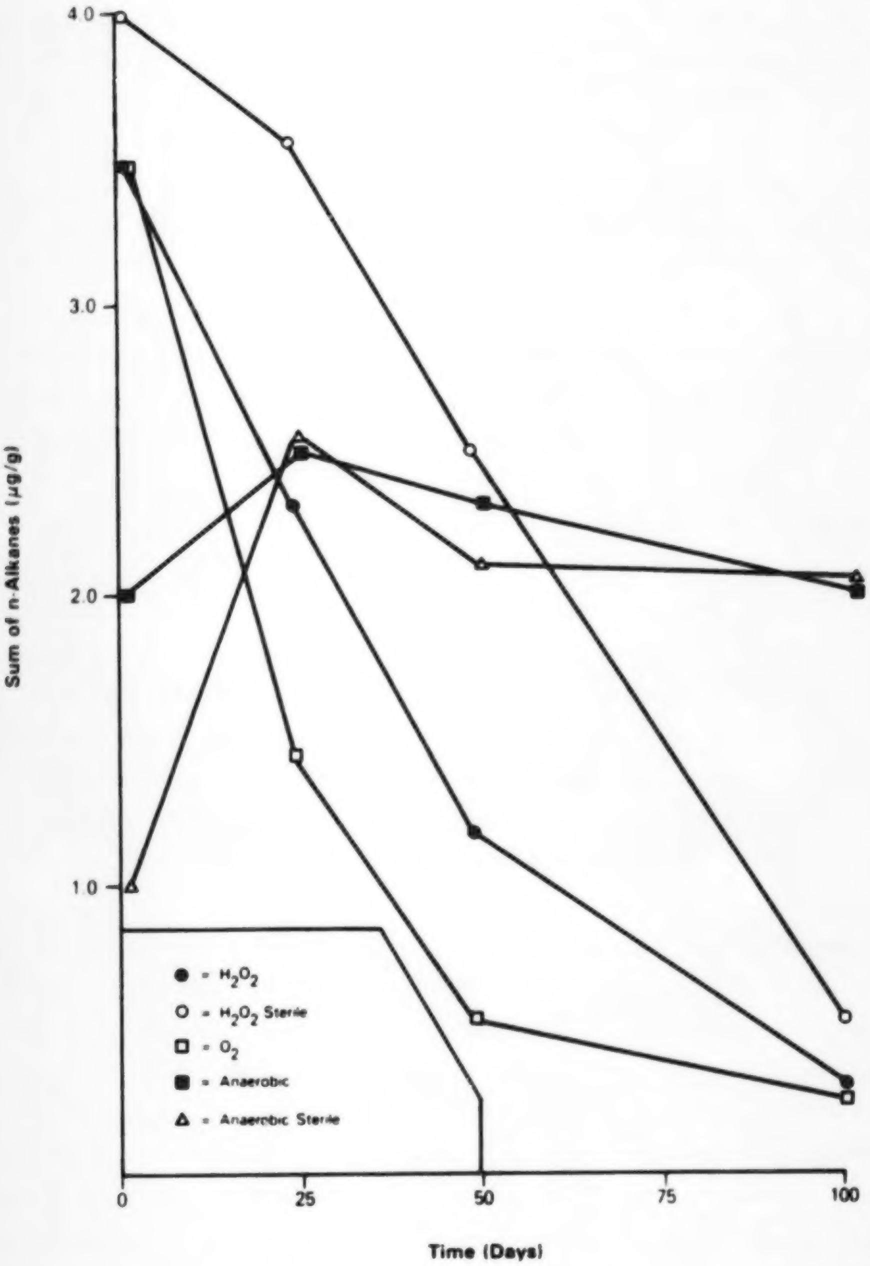

Figure 5. Sum of n-Alkanes Versus Time

showed that microbial degradation was occurring in both the oxygen treated and peroxide treated microcosms.

Aliquots of the sample extracts sacrificed at Day 1, Day 24, and Day 50 were also subjected to electron capture detector (ECD) GC analyses. The presence of components in the "distilled in glass" Burdick and Jackson methylene chloride and other solvents used for sample extraction, in addition to the high levels of petroleum hydrocarbons present, made analysis of electron capture sensitive species extremely difficult. Specifically, the high levels of aliphatic hydrocarbons, which could be detected at levels three orders of magnitude higher by flame ionization detector, tended to coat the electron capture detector, causing integration problems, and a large number of background components could not be resolved. Secondly, the resolved peaks which were present did not correlate with the retention time of pesticide or PCB standards. Finally, the addition of the sodium sulfide to ensure reducing conditions in the anaerobic microcosms caused significant interference problems with the ECD. Large peaks for sulfur were present in all anaerobic chromatographic profiles examined. It should be noted that the interference from the high levels of sulfur is primarily in the anaerobic case. With these and other background interference problems, identification of specific higher molecular weight chlorinated organics by ECD-GC proved to be fruitless. Further, when GC/MS analyses were attempted on the extracts at these concentrations, higher molecular weight chlorinated species were overwhelmed by petroleum hydrocarbon components that were present at levels several orders of magnitude higher. For these reasons, additional ECD-GC analyses of the soil extracts were not performed and, instead, microbial degradation of chlorinated organics occurring in the anaerobic microcosms was monitored by analysis of purgable, lower molecular weight halogenated solvents by purge and trap GC/MS.

A gamma irradiation sterilization treatment was used to differentiate between viable and sterile microcosms. This irradiation process inadvertently destroyed several of the lower-molecular-weight chlorinated organic species being considered in the program. Compounds completely removed by the gamma irradiation included tetrachloroethylene (herein referred to as perchloroethylene, PCE), trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), trans-1,2-dichloroethene (trans-1,2-DCE), 1,1-dichloroethene (1,1-DCE) and 1,1-dichloroethane (1,1-DCA). To ensure that the peaks had not just simply been missed by the GC/MS Incos Data System, visual examination of chromatographic profiles generated from reconstructed ion plots showed that these compounds had been removed by the irradiation process, but were also clearly apparent in the nonirradiated microbial microcosms.

The time-series concentrations for PCE and TCE show rapid degradation under anaerobic conditions. Within 50 days, all PCE and TCE were removed from the anaerobic systems and remained essentially absent from those microcosms with time. As degradation of PCE and TCE occurred over the first 50 days, a concomitant increase in trans-1,2-DCE concentration was observed in anaerobic microcosms. The concentration of trans-1,2-DCE leveled off at the same time as PCE and TCE levels dropped below detection limits. After Day 50, trans-1,2-DCE concentrations decreased under anaerobic conditions while 1,1-DCE and 1,1-DCA concentrations increased. Coefficients of variation (CV) for the replicate determinations were low, in the range of 6 to 12 percent. Triplicate analyses for 1,1-DCA in Day 100 anaerobic systems yielded a mean concentration of 930 ng/g dry weight with a CV of only 3 percent. Levels for this compound at both Day 25 and Day 50 were below instrumental detection limits. Sterile anaerobic controls showed the virtual absence of these chlorinated compounds (PCE, TCE, trans-1,2-DCE, 1,1-DCE and 1,1-DCA) over the entire 100-day experimental period. Graphical representation of these results is included in Appendix D.

These results indicate that biotransformation of PCE and TCE may have occurred under anaerobic conditions, resulting in an increase in trans-1,2-DCE and 1,1-DCE concentrations. In the highly reducing conditions of the anaerobic microcosm, additional reduction by abiotic processes to yield 1,1-DCA may have been possible. These data suggest that this combination of microbial and abiotic processes was occurring in the anaerobic microcosm by Day 100.

Data obtained for chlorobenzene (Figure 6) were somewhat sporadic. However, in general, they suggest more rapid removal of this compound under oxygenated treatments as opposed to anaerobic conditions. Aerobic incubation effected rapid degradation of 1,1-DCE and 1,1-DCA in the first 25 days followed by a rapid increase to above initial levels by Day 100. These results indicate that abiotic processes may have occurred in the aerobic microcosms during the 100-day study period.

From these analyses it can be concluded that, in general, the chlorinated species investigated were preferably degraded under anaerobic conditions in the microcosms prepared from the Kelly Air Force Base samples. In addition, the results suggest production of lower molecular weight chlorinated species from biotransformation of higher molecular weight chlorinated compounds.

An additional objective of the laboratory study was to determine if peroxide treatment would enhance Cr^{+6} formation or metals migration, when implemented in a field program. Therefore a series of trace metal analyses were undertaken with the Day 50 peroxide and oxygen treated microcosms. Table 3 presents concentrations of silver, cadmium, chromium, lead, and antimony in soil and groundwater samples taken initially and following 50 days of incubation with oxygen and hydrogen peroxide.

Results from the metal analyses performed on groundwater samples indicated no significant changes in chromium concentrations between initial and Day 49 microcosm data. Lead concentrations in the groundwater decreased significantly from a mean value of 133 μg/l in the initial groundwater samples to 4.03 μg/l in the Day 49 hydrogen peroxide amended microcosm and 8.3 μg/l in the Day 49 oxygen treated microcosm. Reductions in lead concentrations in the microcosms can most likely be attributed to the formation

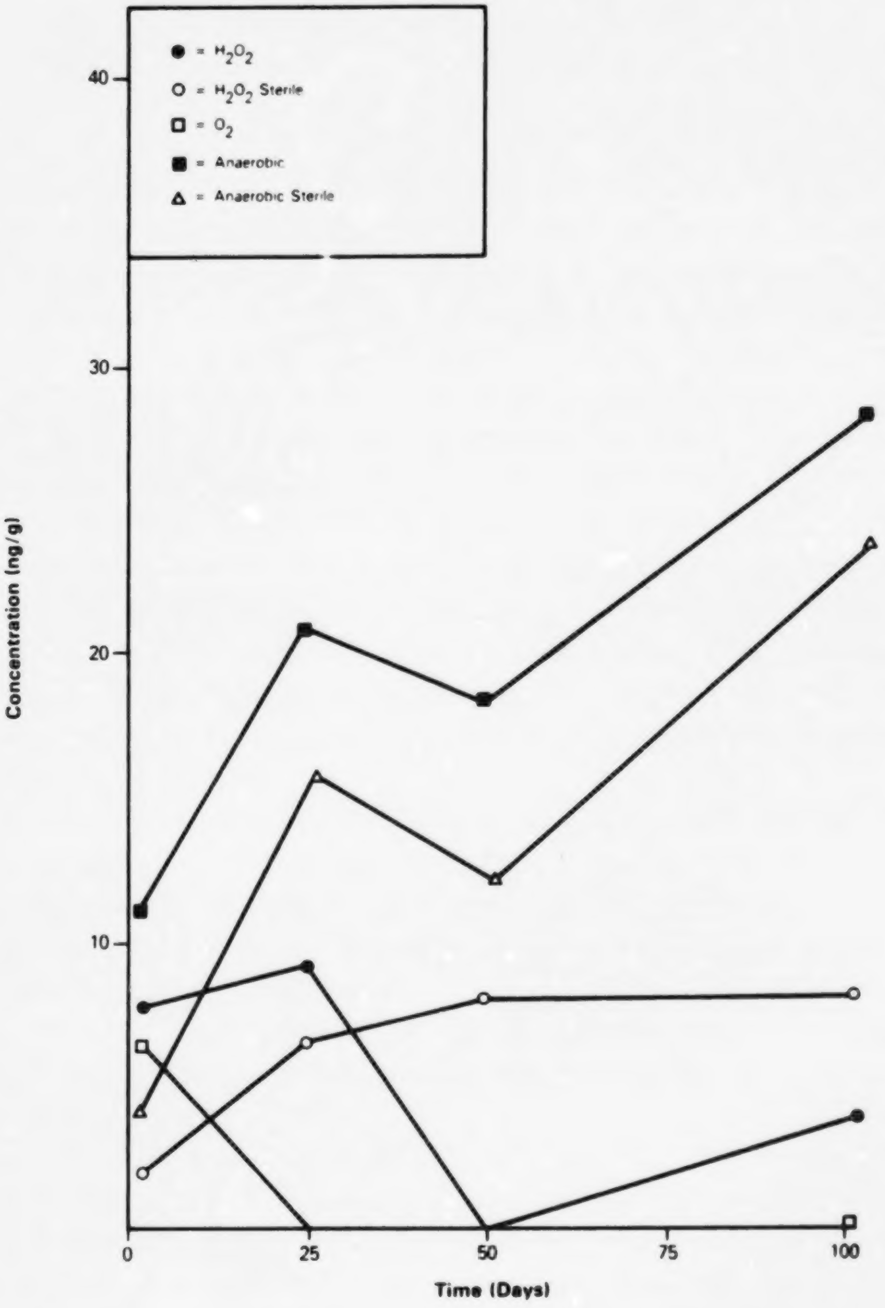

Figure 6. Chlorobenzene Concentration Versus Time

TABLE 3. SELECTED TRACE METAL CONCENTRATIONS IN WATER AND SOILS PRIOR TO AND ON DAY 49 OF THE LABORATORY STUDY

	Water					Soil					
	Well[1] AA	Well[1] BB	Well[1] CC	49-H[2]	49-O[3]	BH-1[4]	BH-2[4]	BH-3[4]	BH-4[4]	BH-5[4]	49-H[5]
Silver	<10	<10	70	0.11	0.10	5.8	4.3	4.6	4.6	4.3	1.3
Cadmium	20	<10	<10	0.38	0.59	5.4	4.0	4.4	5.1	4.7	4.3
Chromium	40	60	20	20.5	24.4	141	58.3	252	67.3	70.1	71.1
Lead	110	120	170	4.03	8.3	51.3	34.3	40.0	42.3	48.8	66.1
Antimony	<50	<50	<50	<5	<5	56.9	47.9	45.8	54.4	47.9	<0.5

All results are expressed in μg/l for waters and μg/g dry weight for soils.

[1] Groundwater sampled July 1984 and analyzed by independent lab.
[2] Water from Day 49 hydrogen peroxide amended microcosm.
[3] Water from Day 49 oxygen amended microcosm.
[4] Soil sampled July 1984 and analyzed by independent lab.
[5] Soil from Day 49 hydrogen peroxide amended microcosm.

of complexes between the functional groups of organic substances and the metal ion or sorption of the metal ions to the surface of organic particles. Humic substances found in soils have the ability to combine with considerable quantities of metal ions which would have resulted in decreased concentrations of metals in the groundwater sampled from the Day 49 microcosms. No definite conclusions can be reached concerning silver, cadmium, and antimony concentrations for the Day 49 microcosm groundwater.

Results from the soil samples collected from Boreholes 1 through 5 and soil samples taken from the Day 49 hydrogen peroxide-treated microcosms show no significant changes in silver, cadmium, chromium, or lead concentrations. These results are shown in Table 3. Antimony concentrations decreased from a range of 45.8 μg/g to 56.9 μg/g in the borehole samples to less than 0.5 μg/g in the soil sampled from the Day 49 hydrogen peroxide-amended microcosm. Reductions in antimony concentrations could be attributed to the formation of reduced complexes caused by the presence of hydrogen peroxide under oxidizing conditions.

In conclusion, groundwater samples collected from Day 49 hydrogen peroxide and oxygen amended microcosms indicated the formation of organo-lead complexes. Formation of stabilized metallic complexes or sorption of metals to the surface of organic particles would not present a problem at the Kelly site unless coagulation or settling occurred, causing clogging of the soils and decreased permeability. Results from the microcosm study also indicated that hydrogen peroxide treatment would not enhance the formation of Cr^{+6} due to oxidation/reduction reactions.

Soil samples collected from the Day 49 hydrogen peroxide-amended microcosms showed decreases in antimony concentrations and suggested that mobilization of this metal ion may be a problem and should be monitored during the demonstration project. Detection limits for antimony in initial groundwater samples were less than 50 ppb (μg/l), while detection limits in the Day 49 microcosm samples were less than 5 ppb (μg/l). Therefore, no definite conclusion could be made regarding any increases in antimony concentrations in the groundwater due to mobilization of the metal ion.

To verify the status of the oxidation/reduction state (redox) of the microcosms and ensure that significant differences were being maintained between aerobic and anaerobic populations, samples were analyzed for redox potential, pH, dissolved oxygen, hydrogen peroxide concentration, and viable growth as a function of time. Summary data for each microcosm type are presented in Appendix D. In general, the hydrogen peroxide treated microcosms showed evidence of bacterial growth throughout the 100-day sampling period and the redox potential was consistently observed to be in the range of +154 to +173mV. Dissolved oxygen levels and pH were also observed to be relatively stable. The redox potential of the hydrogen peroxide sterile control was equal to +160mV after 25 days and ranged from +157 to +167mV after 100 days. Dissolved oxygen concentrations and pH were similar to those observed in the nonsterile peroxide-treated microcosm. The oxygen-treated microcosm also showed a positive redox potential varying from +158 to +170mV during the 100-day period. The anaerobic microcosms showed redox potentials at -142 to -156mV over the 100-day period and in the range of -23 to -91mV for the anaerobic sterile controls. Also, dissolved oxygen concentrations determined in the anaerobic microcosms were lower than those recorded for the aerobic microcosms. The viable growth data also suggested an absence of microbial growth on plate counts obtained from sterile microcosms sacrificed during the program. An aliquot for microbial growth determinations was obtained from each microcosm at the time of sacrifice to verify the presence or absence of viable bacterial populations. These data verified that the gamma-irradiation sterilization technique was used successfully. Based on the results presented, the redox potential could be maintained in either an oxidized or reduced state by the addition of the chemical treatments utilized and both sterilized and viable cultures could be maintained throughout the study period.

The results of this program demonstrated that: (1) in situ microbial populations were capable of degrading the contaminants present in the soil of Kelly Air Force Base; (2) active cultures were developed that demonstrated degradation of aliphatic and aromatic hydrocarbons under aerobic conditions and chlorinated hydrocarbons under anaerobic conditions; (3) oxygen treatment as well as introduction of hydrogen peroxide worked equally well for degradation of petroleum-type compounds; and (4) results from the biodegradation study also suggested the biotransformation of PCE and TCE to the lower molecular weight chlorinated aliphatic compounds, trans-1,2-DCE and 1,1-DCE, under anaerobic conditions. Chlorinated hydrocarbon degradation under anaerobic conditions has been reported previously in the literature (Reference 17).

B. PERMEABILITY STUDIES

Permeability studies were conducted on soil samples collected from the Kelly site. Detailed results are found in Appendix F and are summarized below.

Soil samples were collected from Borehole A for chemical characterization. Soil samples utilized for the permeability studies were collected from Borehole B, shown on Figure 7, and groundwater samples were collected from monitoring well AA and Borehole 12. Groundwater samples were analyzed for cations, anions, nutrients, electrical conductivity, and pH. Soil samples collected from Borehole A were analyzed for cations, anions, and nutrients, and soil samples collected from Borehole B were analyzed for particle density, bulk density, porosity, pore volume and particle size distribution. A complete list of groundwater and soil parameters and analyses is given in Appendix F.

Groundwater samples labeled KWB&A were collected from Well AA and groundwater samples labeled JRB&A were collected from Borehole 12. Both samples indicated high levels of carbonates and calcium. These components were

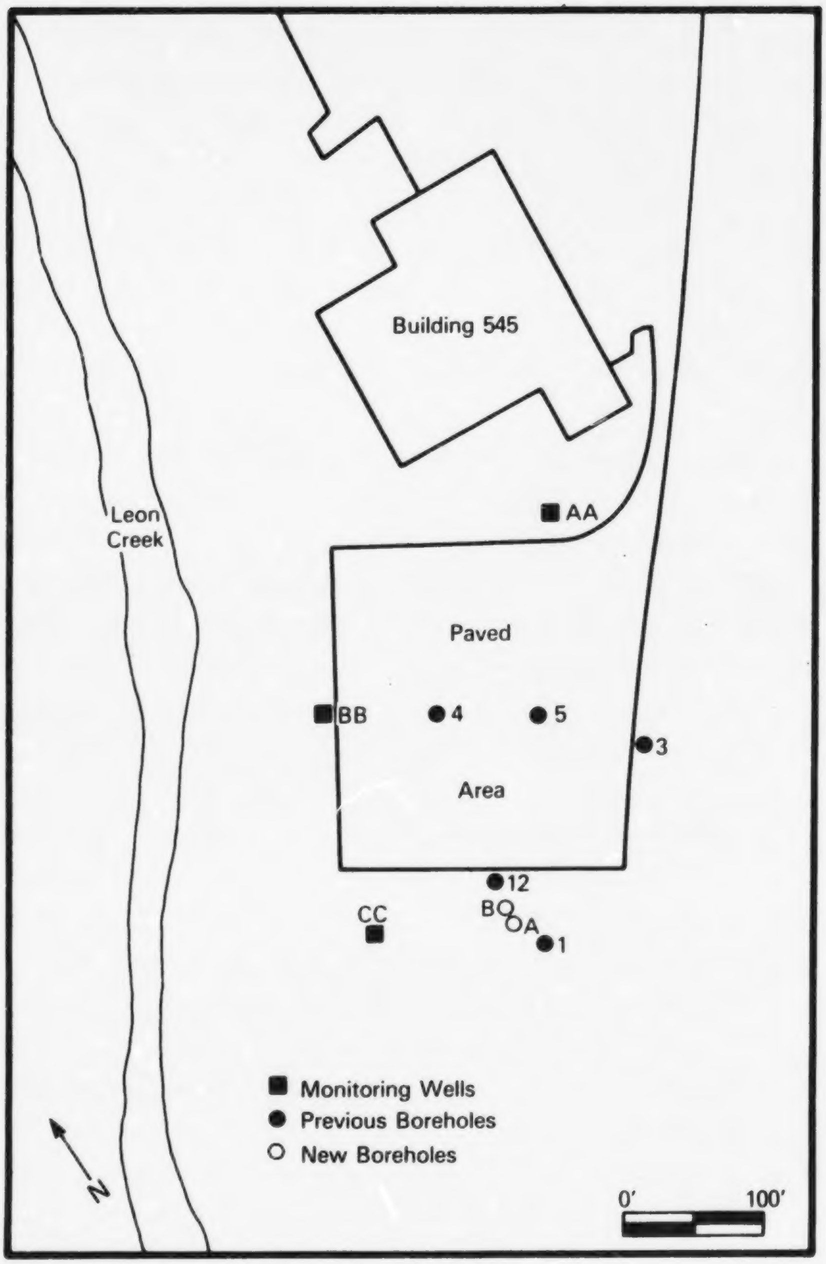
Building 545
AA
Leon Creek
Paved
BB
4
5
3
Area
12
CC
B
A
1
■ Monitoring Wells
● Previous Boreholes
○ New Boreholes
N
0'
100'

Figure 7. Groundwater and Soil Sampling Locations for Permeability Study

expected to reduce the mobility of phosphates and the stability of peroxide moving through soil samples. Total salt concentrations and pH values were at levels which were not expected to inhibit microbial growth or in situ microbial degradation of the contaminants present at the site.

Results from the chemical analyses of soil samples indicated relatively high levels of soluble and exchangeable calcium, capable of reducing the mobility of phosphates. In addition, the levels of calcium were considered high enough to hasten the decomposition of hydrogen peroxide in the formation. High pH and alkalinity levels present in the soil were also expected to reduce phosphate mobility and hasten hydrogen peroxide decomposition. Concentrations of reduced metals (Fe and Mn) detected in the soil samples were relatively low. Therefore, significant decomposition of hydrogen peroxide would not occur due to oxidation/reduction reactions with the reduced metals (Fe and Mn) and hydrogen peroxide. Relatively low levels of nitrogen were detected in the soil samples. Therefore, it was concluded that nutrient supplementation should be provided to enhance the degradation of organics by the microbial population present in the subsurface.

Table 4 shows physical properties of the soil samples collected from Borehole B which were used in the permeability tests. Both samples contained more than 50 percent gravel. Approximately 30 percent of the particles smaller than gravel were clay, while 39 to 47 percent were classified as sand-sized particles. The soils were classified as very gravelly clay loams.

Triaxial permeameters were used to determine the permeability of two undisturbed soil cores collected from a 10 and 13 foot depth in Borehole B. Each triaxial permeameter was connected to a pressure control panel where both the confining pressure and pressure head were regulated.

The two undisturbed soil samples were prepared for testing by trimming to a 10 cm diameter and leveling the top and bottom as much as practicable. A porous stone was placed at both ends of the sample. The sample and the

TABLE 4. PHYSICAL PROPERTIES OF THE SOIL

Parameter	Soil Sample Identification	
	Soil Sample #1	Soil Sample #2
Particle Density (gm/cm^3)	2.71	2.74
Bulk Density (gm/cm^3)	2.22	2.13
Porosity	0.18	0.22
Pore Volume (cm^3)	110.79	138.23
Clay (% <0.002 mm)	14.4 (29.1)*	14.0 (33.8)*
Silt (% 0.002-0.05 mm)	15.7 (31.8)*	7.6 (18.4)*
Very Fine Sand (% 0.05-0.01 mm)	3.7	2.7
Fine Sand (% 0.1-0.25 mm)	3.6	3.1
Medium Sand (% 0.25-0.5 mm)	2.9	2.7
Coarse Sand (% 0.5-1.0 mm)	3.4	4.2
Very Coarse Sand (% 1.0-2.0 mm)	5.7	7.1
Total Sand (% 0.05-2.0 mm)	19.3 (39.1)*	19.8 (47.8)*
Gravel (>2.0 mm)	50.7	58.7
USDA Soil Classification	Very Gravelly Clay Loam	Very Gravelly Sandy Clay Loam

*Percent of particles smaller than 2.0mm porous stone were set on a stainless steel pedestal and a stainless steel cap was placed on the top stone. The cores and porous stones were then enclosed in flexible membranes and O-rings were used to hold the membrane to the stainless steel cap and pedestal. Cylinders were used to supply permeant liquid under controlled pressure to the soil sample. Confining pressure was applied to the outside of the membrane surrounding the soil samples to duplicate the normal lateral stress at a 13 foot depth below ground surface and to prevent side-wall flow between the soil and the membrane. The top of the sample was under normal, outside air pressure while the bottom was under the pressure of the water in the cylinders (10 PSI). The soil samples were permeated by groundwater from monitoring Well AA until stable permeability values were obtained.

Formulated nutrients (Restore® 375K) and stabilized hydrogen peroxide (Restore® 105) (proprietary products for which patents are pending), supplied by FMC Corporation, were mixed with groundwater from Well AA to form a nutrient solution used for nutrient breakthrough determinations. Nutrient salts were added in a concentration of 500 mg/l, while 100 mg/l of hydrogen peroxide was added to the groundwater. The resulting nutrient solution was permeated through the soil samples after stable baseline permeability values were obtained with groundwater. Leachate was collected periodically and analyzed to determine the effect of the nutrient solution on the soil permeability. Samples of the leachate were analyzed for chloride, phosphate, and peroxide content. The concentrations of leachate constituents were used to develop breakthrough curves for two soil samples.

Initial permeability of the soil was determined as 1×10^{-6} cm/sec (0.003 ft/day). Note that samples were taken from the vicinity of Well P-2, an area of low permeability (see Table 1). Following 0.21 to 0.25 pore volumes of nutrient and peroxide supplemented groundwater ("nutrient solution"), concentrations of phosphate, chloride, and hydrogen peroxide were detected in the leachate. Breakthrough curves are shown in Figures 8 and 9. Raw data used to develop the breakthrough curves are given in Appendix F.

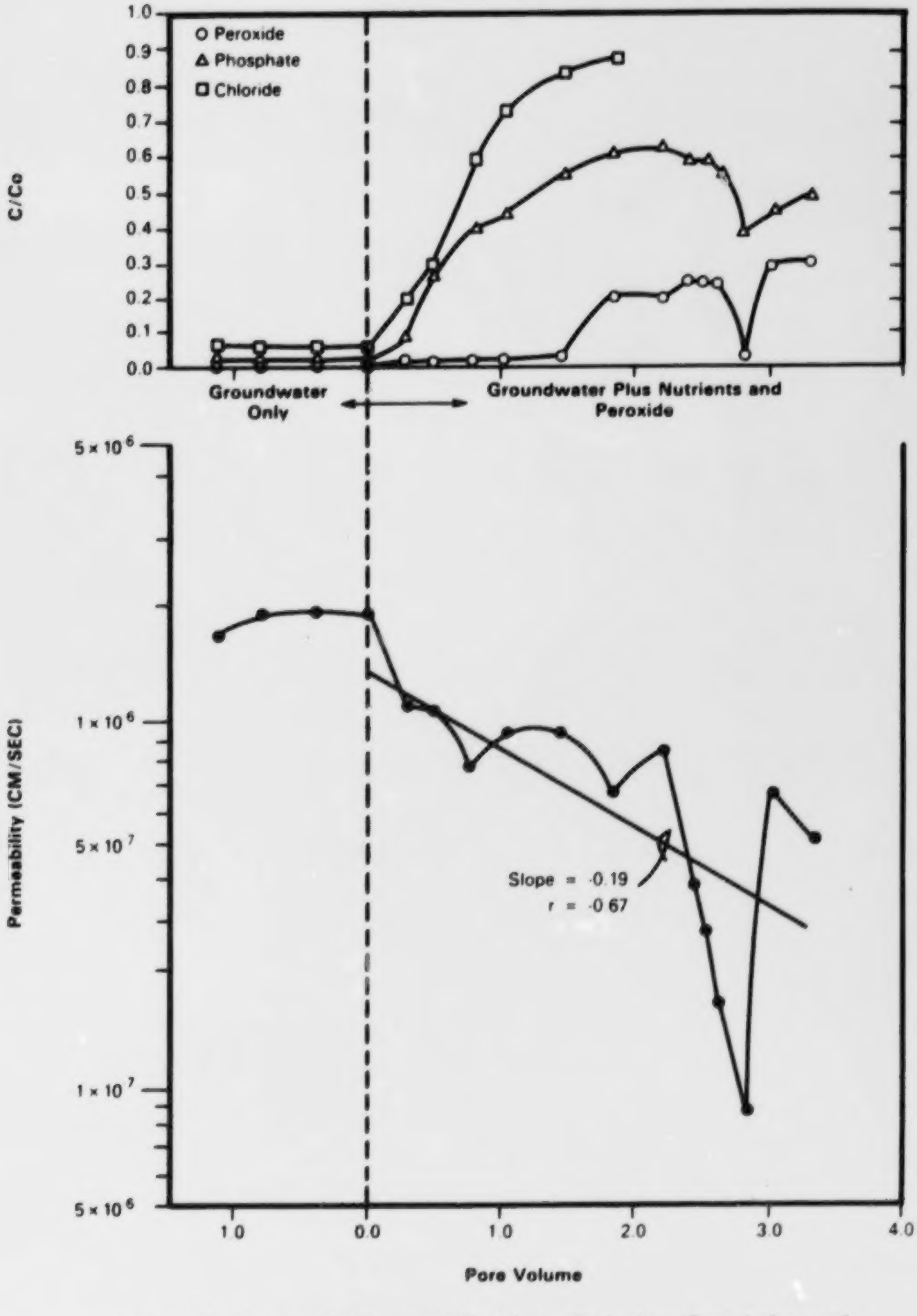

Figure 8. Permeability and Nutrient Solution Breakthrough Curves for Soil Sample Number One

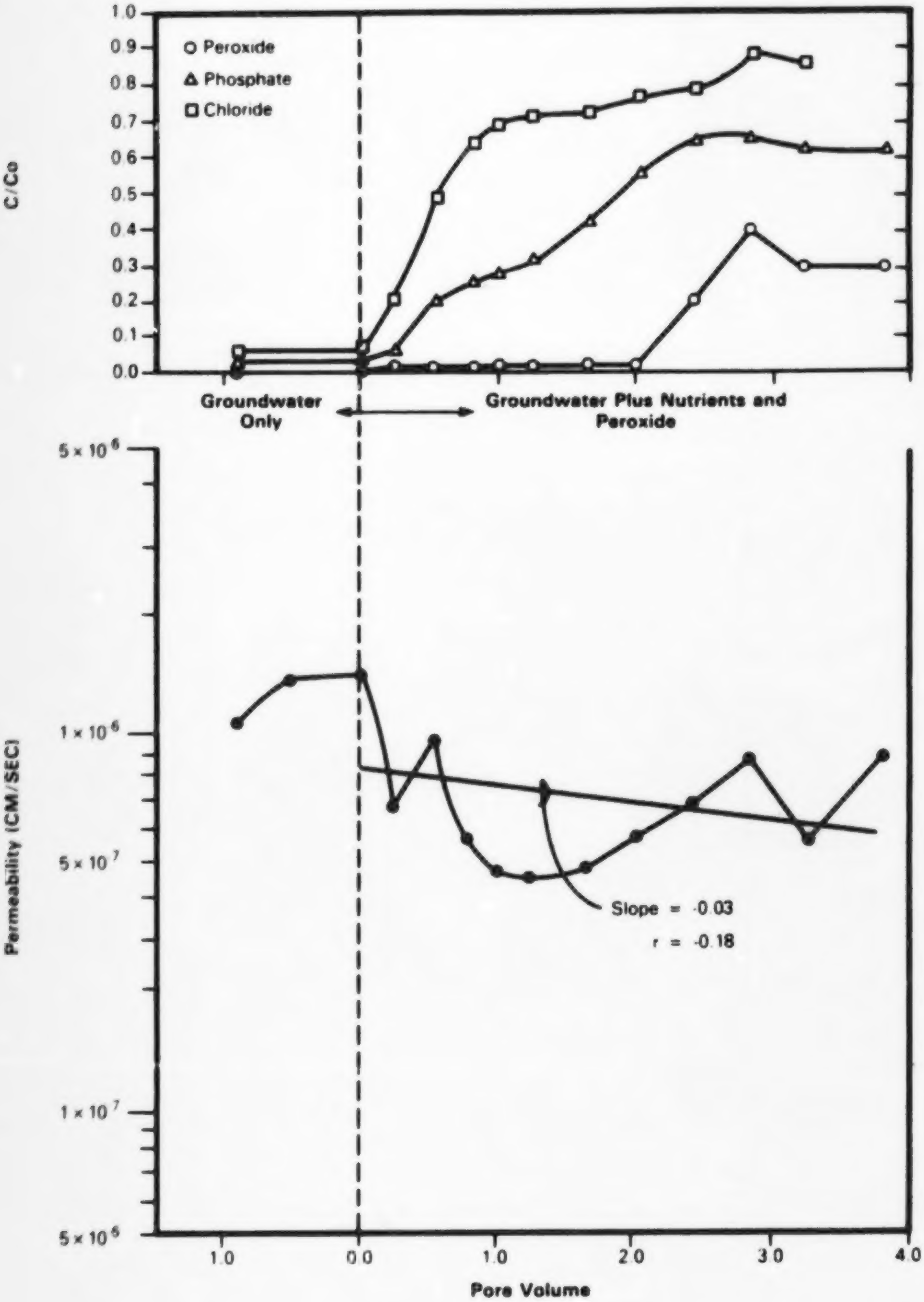

Figure 9. Permeability and Nutrient Solution Breakthrough Curves for Soil Sample Number Two

Leachate chloride concentrations reached levels close to initial chloride concentrations ($C/Co = 0.86$) due to little chloride attenuation by the soils. Water-soluble phosphate concentrations in the leachate are shown in Figures 8 and 9 and indicate that phosphate was significantly attentuated by the soil. Reduced mobility of phosphate may have been caused by the formation of insoluble calcium phosphate complexes.

Hydrogen peroxide breakthrough curves show that hydrogen peroxide did not reach values greater than 40 percent of the concentration in the nutrient solution after passage of greater than three pore volumes of leachate. Hydrogen peroxide decomposition in the soil most likely caused loss of transport through the permeameters.

Changes in soil permeability during passage of three pore volumes of nutrient solution are also shown in Figures 8 and 9. Results indicated a greater than 99 percent certainty that the nutrient solution caused a decrease in soil permeability for Soil Sample 1. A decrease in permeability of approximately 5 to 10 x 10^{-7} cm/sec occurred during the three pore volume test period. Soil Sample 2 appeared to exhibit a slightly decreased permeability due to nutrient and peroxide addition. However, statistical analysis did not suggest the decrease was significant. Statistical analysis was performed by fitting a least squares regression line through the data. The Pearson correlation coefficient, r, was used to measure the degree of linearity of the permeability data.

The soil analyses and permeability studies indicated that calcium phosphate precipitation may cause a reduction in the permeability of soils at the Kelly site. Also, dissolution of calcium carbonate binding agents by the hydrogen peroxide may increase the mobility of the clays and cause further clogging of the soil at the borehole walls.

C. NUTRIENT AND PEROXIDE STABILITY STUDIES

Restore® 105 Microbial Nutrient, a proprietary stabilized hydrogen peroxide solution, is being provided by FMC Corporation, Princeton, NJ. The peroxide solution is supplied as 35 percent H_2O_2 and diluted prior to distribution in the treatment system. Peroxide stability tests were performed by FMC Corporation on a slurry of site water and soil. Results from the stability test indicated 10 percent loss of H_2O_2 in 1 hour and 90 percent loss in 24 hours. This rate of hydrogen peroxide decomposition is within a range considered acceptable for site remediation in permeable soils. However, because the soils at the Kelly site have a low permeability in certain areas, it was concluded that the relatively high rate of peroxide decomposition may affect the concentrations of peroxide required at the site.

Restore® 375K, also provided by FMC Corporation, is a proprietary nutrient formulation containing ammonium chloride and potassium salts of ortho- and polyphosphate. The nutrient is supplied as a liquid concentrate (23 percent) and either diluted prior to distribution or added in a batch mode in order to achieve the desired concentrations of nutrients. Tests were conducted with Restore® 375K to determine the nutrient adsorption potential of the soil. Soil composites were obtained from the demonstration site and slurried with site water and spiked with a concentrate of Restore® 375K Microbial Nutrient. The slurry was filtered, slurried again with site water spiked with nutrients, and filtered using 1 percent KCl solution. The filtrates were analyzed for ammonia and phosphate concentrations.

Results from the adsorption studies indicated both ammonia and phosphate adsorption on the soil composite was appreciable. However, ammonia and phosphate could be leached from the soil, indicating that movement through the formation should occur. A 100-gram soil sample retained 75 percent of the phosphate from a 100 ml solution containing 8000 ppm of phosphate. The same soil retained 35 percent phosphate from a second 100 ml solution. A large portion of the phosphate was recovered from the soil by successive washes with 10 percent KCl. Ammonia retention was 60 percent and 40 percent from successive solutions containing 500 ppm NH_3. A large portion of the ammonia was recovered with successive 1 percent KCl washes.

Nutrient precipitation studies were conducted on groundwater samples taken from the demonstration site. Restore® 375K was mixed with a groundwater sample. After 4 hours, a faint cloudiness was observed. Following 24 hours, a period much longer than the time between mixing and injection, approximately 16 mg/l of precipitate was obtained. This corresponds to less than one pound of material during the demonstration period. It was concluded from these nutrient precipitation studies that precipitation of calcium phosphate should not be a problem. However, changes in water composition, especially calcium concentrations, temperature, or pH, could affect the rate and extent of precipitation. Modifications of the nutrient formulation or addition design could be made if changes occurred during operation of the demonstration.

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SECTION IV

FIELD DEMONSTRATION OF IN SITU BIODEGRADATION

This section presents an overview of the design and the construction of the treatment system and the soil and groundwater sampling that was conducted in support of this effort. The problems that were encountered during the demonstration are also discussed in this section.

A. TREATMENT SYSTEM DESIGN, CONSTRUCTION, AND STARTUP

A major effort and expense for developing the treatment system was establishing the number, configuration, and design, and installing the pumping wells and gravity injection wells that are used for circulating groundwater for this system.

Although the actual biodegradation of contaminants takes place underground, an aboveground portion of the system is needed for groundwater circulation and nutrient addition. The following sections present the design, construction, and startup procedure for the system.

1. Treatment System Design

Because of the varied geologic conditions that exist at the Kelly AFB site, it was determined that treatment would be limited to a small area in order to achieve results in the timeframe available for conducting the demonstration and that a system of pumping and gravity injection wells would be best suited for such a limited area. Water would be pumped from the ground and mixed with a nutrient and hydrogen peroxide solution, then returned to the perched aquifer at a separate location.

The configuration and number of pumping and injection wells were determined,using previously accumulated field test data to develop a two-dimensional geohydrologic model simulating the flow of groundwater at the site in response to operating a pumping/injection system. Because of concern for water quality in the nearby Leon Creek, the model was run to simulate a steady-state operation of the system for 60 days to verify that the creek would not be impacted. The model was calibrated to match observed field permeability test data obtained in early 1985 and assumed a homogeneous isotropic aquifer of uniform thickness. A finite difference grid was set up for the site, with pumping and injection wells at the grid points. The site transmissivity and storage coefficient were input, along with sample flow values at grid points, and initial water levels. The system is then turned "on" and the model determines the change in water levels over time. The output shows water levels at each node on the grid for a specified time. A site configuration was chosen to keep water levels stable and minimize the effect outside the system. Detailed results of this model are presented in Appendix G.

The resulting system, illustrated in Figure 10, was implemented at the Kelly AFB site. The system consists of nine pumping wells and four injection wells arranged in a grid pattern within a circular area 60 feet in diameter and was designed so that each injection well would be surrounded by four equidistant pumping wells 15 feet away. The pumping wells are 4 inches in diameter and the injection wells are 6 inches in diameter. In addition, 2-inch monitoring wells were placed,one upgradient and one downgradient of the treatment site.

Each pumping well contains a durable, 0.5-horsepower, submersible well pump which is designed to run continuously for the life of the project. It was not feasible to use a pump that is capable of operating at the extremely low flow rates required at this site. Therefore, it is necessary to pump water from the well at a much higher rate than is needed, and return the unused portion to the well. This operation is achieved through a

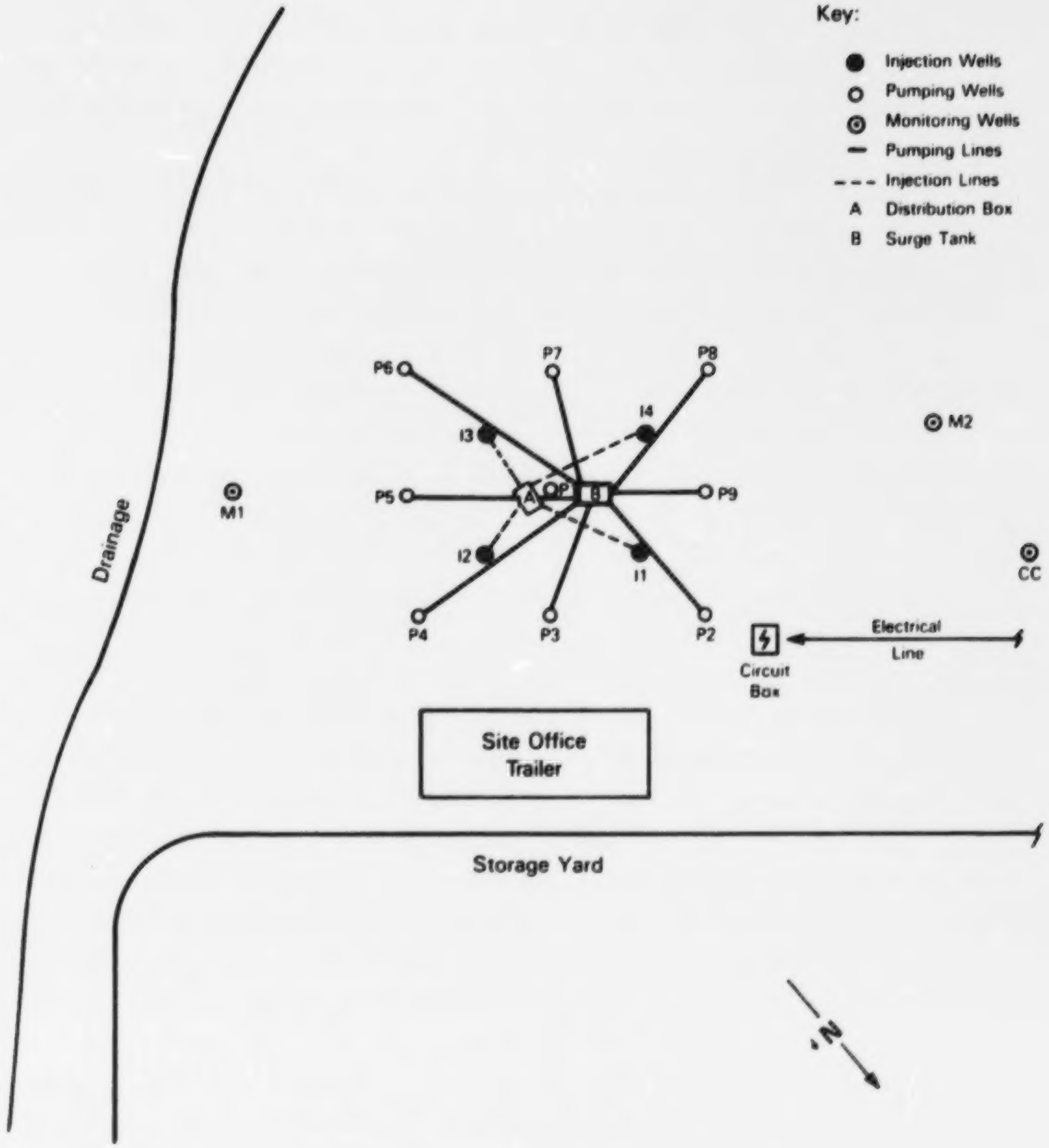
Key:
● Injection Wells
○ Pumping Wells
⊙ Monitoring Wells
— Pumping Lines
- - - Injection Lines
A Distribution Box
B Surge Tank
P6
P7
P8
I3
I4
M2
P5
A
P
B
P9
M1
Drainage
I2
I1
CC
P4
P3
P2
Electrical
Line
Circuit
Box
Site Office
Trailer
Storage Yard
N

Figure 10. Plan View of Site Configuration
(Not to Scale)

dual-valve system located above the well casing. Figure 11 illustrates a typical pumping well. The release valve is set to allow the desired amount of flow into the system, while the check valve provides the necessary back pressure on the pump and allows the overflow to pass into the discharge line that returns this water to the well.

Once groundwater enters the system, it travels to a central surge tank. Any overflow from the surge tank is transferred by pipe into drums for storage. A valve at the bottom of the surge tank releases water at a controlled rate into a pipe into which specially formulated nutrient and a stabilized hydrogen peroxide solution (FMC Restore® 375K and 105, respectively for which patents are pending) are introduced. This flow then passes through a section of baffled pipe to facilitate mixing before it enters a distribution box for dividing the flow among the four injection wells. Three of the four lines to the injection wells have valves to control flow rates into the wells, while the fourth line remains unobstructed to prevent a backup of water in the distribution box.

All of the piping, valves, and fittings used to construct the system are made of PVC, which should not affect the results of this demonstration in any negative manner. Other than the pumps and decontaminated monitoring probes, PVC will be the only material present in the wells. Each pump is individually controlled by dedicated electrodes that sense high and low water levels in the well. When the level of water in the well drops below a safe level for pump operation (0.5 foot above the intake), the pump automatically is shut off. Once the well recharges, the pump will once again be turned on. A similar system is installed in the surge tank to prevent overflow. At high level, a switch is thrown to cut off all pumps until the water in the surge tank reaches a specified lower level. This system prevents overflow while allowing for continuous injection.

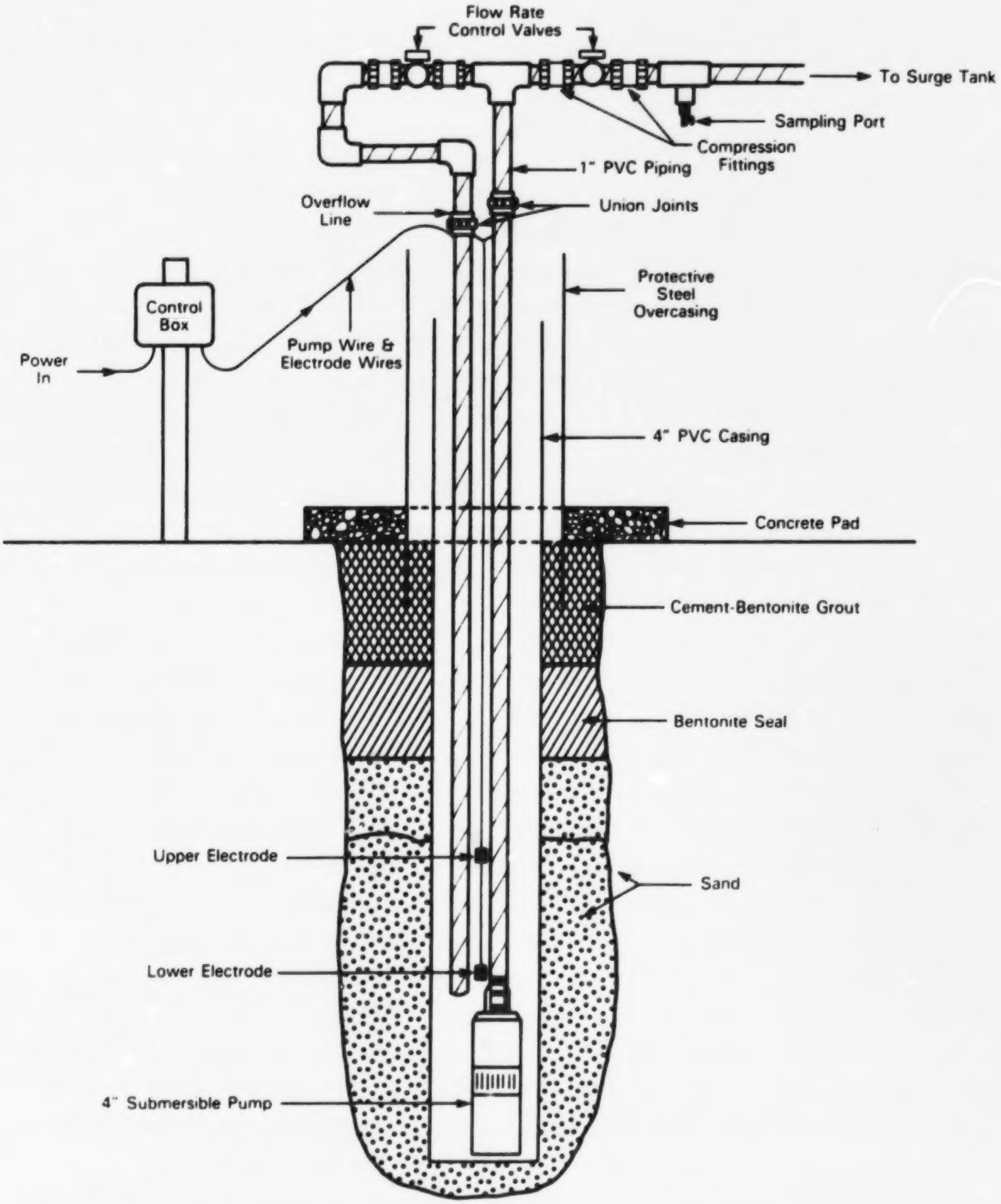
Flow Rate Control Valves
To Surge Tank
Sampling Port
Compression Fittings
1" PVC Piping
Overflow Line
Union Joints
Protective Steel Overcasing
Control Box
Power In
Pump Wire & Electrode Wires
4" PVC Casing
Concrete Pad
Cement-Bentonite Grout
Bentonite Seal
Upper Electrode
Sand
Lower Electrode
4" Submersible Pump

Figure 11. Cross Section of a Typical Pumping Well (Not to Scale)

2. Treatment System Construction

This system was constructed in April and May of 1985. Figure 10 shows a plan view of the treatment system configuration. The first phase of construction involved the drilling of wells. Existing test wells TP-01 and TO-02 (see Appendix B) were used in the system and renumbered as I1 and P2, respectively. The site was then measured and stakes were placed at each well location. It was decided that existing well CC could be used as a monitoring well for the system, along with the new wells to be installed. The name "CC" was retained to avoid confusion.

Each well was drilled using identical procedures. The drill rig was positioned as close to the well locations as possible. However, the drill rig could not be positioned with pinpoint accuracy, therefore, well locations differ somewhat from the designed locations. The first step in well installation was to steam clean the drill rig and bit. This was performed for each new well to reduce the potential for contamination. The drill rig was of mud rotary type and all cuttings and drilling mud were left on-site. When the well reached a measured depth of at least 30 feet, standing water and mud were removed using a large steel bailer (steam cleaned prior to use). The PVC casing was then assembled from 5-foot sections, the bottom 15 feet of which were slotted, and lowered into the hole. Clean water was forced into the well to clear away more fines and loose material and sand was then slowly poured outside the well casing and allowed to settle to a final height of 1.5 feet above the top of the slotted casing. Bentonite pellets were added above the sand to bring the level up another 1.5 feet and allowed to hydrate for 30 minutes. A cement bentonite grout was then added and brought to within 2 feet of the surface. The grout was then left overnight to set. The last step in well construction was to set the protective steel overcasing and guard pipes into concrete bases.

Following the successful construction of the wells, each well was carefully developed to remove all of the remaining fines. This was performed by first using an air compressor to clean out the screens with forced air and suspend the fines through agitation. A jet pump was then used to remove the dirty water from the well until no more fines were present.

Construction of the piping system was performed in sections. All connections were heat-welded in order to avoid the use of glues, which could introduce unwanted organic contaminants into the system. All pipes, joints, and valves were constructed of PVC. All piping runs were carefully measured and each of the welded subsections of pipe were welded together. The pumps and pump lines were then lowered into the pumping wells. The pumps were each wired to a control box and tested for proper operation. Once the pumps were operating correctly, the upper section of piping containing the two control valves and the sampling port was connected to the pump line using a union joint. The overflow return line was then lowered into the well and also attached with a union joint. Once the pumps were installed, tests were performed for each well to determine optimum pumping rates.

The surge tank, indicated in Figure 10 as "B," was constructed from a polyethylene 55-gallon drum laid on its side so that the bottom bung could be used to release water at a controlled rate and the top bung could be used to release overflow. One inch holes were drilled in the top to allow water from the pumping wells to enter. The distribution box was constructed from a PVC box in which four outflow holes and one inflow hole was drilled. A top was also made of PVC to keep rainwater and other substances from entering the system. Wooden platforms were constructed to elevate each container to a predetermined height to provide gravity flow for injection. The containers were then mounted and leveled. A pipeline was fashioned to connect the surge tank to the distribution tank. This line included a ball valve to meter flow from the surge tank followed by a feed inlet for nutrients and hydrogen peroxide and a 1-foot section of baffled 2-inch PVC pipe to help facilitate mixing of the nutrients and hydrogen peroxide solution with groundwater. Finally, cross pipes were installed to connect each of the injection wells with the central distribution system. Lateral support was provided by a number of wooden poles firmly anchored in the ground.

3. System Startup

Following completion of construction, each pump was set to a rate determined from the pumping tests to result in steady-state yield. Pumping rates were highly variable because of the heterogeneity of the demonstration site and the total flow from all nine wells was only slightly more than one gallon per minute because of low yield of the perched aquifer. This flow was distributed equally among the four injection wells. However, the injection wells could not all accept the equally divided flow and the flows were adjusted to the maximum that could be accepted by each well. Groundwater was circulated through the system for several days prior to the introduction of nutrients so that flow rates could be readjusted and any other problems with the system could be worked out. Several pumps had to be removed during this testing period to be cleaned, because of fines remaining in the wells after development.

After several days of recirculating groundwater, a specially formulated nutrient solution was introduced into the system. This nutrient solution was introduced to adjust the pH of the system, ensure an excess of phosphate that would assist in hydrogen peroxide stabilization, increase emulsification of insoluble organics, and fortify the microbial populations in order to minimize any adverse effects of the hydrogen peroxide. Stabilized hydrogen peroxide addition was commenced approximately 2 weeks later at a total concentration of 100 ppm in the groundwater injection flow. Hydrogen peroxide concentrations were increased by 100 ppm every 2 weeks to achieve a final total concentration of 500 ppm in the injected groundwater.

A system was set up to introduce both the nutrient and peroxide solution together. Once both solutions are mixed together in 30-gallon drums, a small chemical feed pump draws the solution at a prescribed rate and feeds it via flexible tubing to the line between the surge tank and the distribution box.

B. SAMPLING AND MONITORING

The following sections discuss the soil and groundwater sampling conducted during system construction and at regular intervals throughout the project. Other groundwater monitoring data that is being collected is also described.

1. Soil Sampling

Soil samples were collected twice during the demonstration project and were analyzed for chemical and biological parameters. Initial soil samples were collected during well drilling, in late April, 1985. The second round of soil samples was collected between 30 July and 8 August, 1985.

Soil samples were collected using a standard, thin-walled sampling tube (Shelby tube). Each tube was first scrubbed with a wire brush and laboratory detergent and then steam-cleaned. The samples were then rinsed in isopropyl alcohol and again steamed. After sample collection and extrusion on a precleaned extruder, the samples were subdivided and stored in sterile containers at 4°C until analysis.

The soil samples were split into three portions as follows: (1) two 750 ml glass jars used for total phosphates, inorganic orthophosphates, hydrocarbons, and priority pollutants (metals, volatile fraction, base/neutral extractables, and acid extractables); (2) four small glass jars used for microbiological counts; and (3) one small plastic bag for field soil analyses.

Field analyses were performed on soil samples with a field test kit. Field analyses included pH, calcium, iron, magnesium, manganese, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, phosphate, and sulfate.

2. Groundwater Sampling and Monitoring

Hydraulic, chemical, biological, and physical parameters are monitored regularly throughout the duration of the demonstration project to determine process performance. Three monitoring wells along the periphery of the demonstration site are used to monitor water level changes and the potential migration of injected chemicals. Monitoring was also performed at each of the pumping and injection wells.

a. Hydraulic Parameters

Water level measurements and groundwater, nutrient, and peroxide flow rates were recorded daily. Due to low injection rates in wells I-1 and I-2, the system was shut down each evening to prevent overflow and to allow standing water in the well casings to drop to normal levels. Prior to initiating pumping each day, static water levels were measured for each of the pumping, injection, and monitoring wells. The measuring device was decontaminated between each well to prevent cross-contamination of the wells. Measurements were recorded using the top of each well casing as the reference point. Water level measurements were not recorded on several wells during the demonstration startup period because of temporary overflow conditions or other operational problems.

Groundwater flow rates were measured as groundwater emptied into the distribution box. Nutrient and hydrogen peroxide flows to the distribution pipe were redirected past the baffled pipe section, directly into the distribution box during groundwater flow measurement. Nutrient and hydrogen peroxide flow measurements were recorded daily from each of the nutrient and peroxide storage tanks.

b. Chemical, Biological, and Physical Parameters

An extensive groundwater monitoring program was implemented during the demonstration period. The monitoring schedule is outlined in Table 5. The parameters selected for monitoring are indicators of process performance. Groundwater samples were collected from pumping wells from a sampling port located on the discharge side of the pumping/recirculation piping system.

Groundwater samples were collected from injection and monitoring wells with a PVC bailer. The bailer was decontaminated following the collection of each groundwater sample. The bailer was thoroughly washed with Alconox solution, rinsed with distilled water, and the uphaul string was changed after the sampling of each well.

Groundwater samples from each well were collected for field testing in 250 ml clear glass sample bottles. Dissolved oxygen, temperature, conductivity, and pH were measured in the field immediately following groundwater sample collection. Measurements were recorded from portable field meters. Groundwater samples were stored at 4°C until field test kit analyses were performed. Field test kits were used for analyses of the following parameters: alkalinity, acidity, chloride, total hardness, ammonia (NH_3-N), nitrate nitrogen (NO_3-N), sulfate, phosphate, lead, chromium, and H_2O_2.

Groundwater samples were collected and analyzed for total hydrocarbons and priority pollutants (metals, volatile organics, base/neutral extractables, and acid extractables) twice during the demonstration period. Initial groundwater samples were collected in late May 1985, following well construction and development. Initial groundwater samples were collected to establish baseline values of contaminants present at the demonstration site. The second round of groundwater samples was collected 8 August 1985.

TABLE 5. GROUNDWATER MONITORING SCHEDULE

PARAMETER	SAMPLING FREQUENCY			
	CENTER EXTRACTION WELL	PERIPHERY EXTRACTION WELLS (8)†	INJECTION WELLS (4)†	MONITORING WELLS (3)†
TEMPERATURE, CONDUCTIVITY	2/WEEK	2/WEEK	2/WEEK	2/WEEK
DISSOLVED OXYGEN, PH	2/WEEK	2/WEEK	2/WEEK	2/WEEK
ALKALINITY	MONTHLY	MONTHLY	WEEKLY	MONTHLY
ACIDITY	MONTHLY	MONTHLY	WEEKLY	MONTHLY
CHLORIDE*	3/WEEK	3/WEEK	2/WEEK	MONTHLY
TOTAL HARDNESS	MONTHLY	MONTHLY	WEEKLY	MONTHLY
NH_3 - N*	3/WEEK	3/WEEK	WEEKLY	MONTHLY
NO_3 - N	WEEKLY	WEEKLY	WEEKLY	MONTHLY
SO_4	WEEKLY	WEEKLY	WEEKLY	MONTHLY
PO_4 (ALL FORMS)*	3/WEEK	3/WEEK	WEEKLY	MONTHLY
HEAVY METALS:				
LEAD	MONTHLY	MONTHLY	-	MONTHLY
CHROMIUM	MONTHLY	MONTHLY	-	MONTHLY
H_2O_2	2/WEEK	2/WEEK	WEEKLY	WEEKLY
TOTAL HYDROCARBONS	2 TIMES +	2 TIMES +	2 TIMES +	2 TIMES +
PRIORITY POLLUTANTS	2 TIMES +	2 TIMES +	2 TIMES +	2 TIMES +
MICROBIOLOGICAL SCREENING	2/MONTH	2/MONTH	MONTHLY	2/MONTH

+ Sampling and analyses will occur at beginning of study and at completion of study period.

* Sampled daily for first month.

† Refers to the number of each type of well.

Quality assurance/quality control (QA/QC) groundwater samples were collected for analysis of priority pollutants during the second round of sampling. One replicate sample and one field blank were included for analysis. A bailer wash sample was not required because samples were collected from pumping wells where bailing was not required.

Methods used for collection of groundwater samples for priority pollutant and hydrocarbon analysis included decontamination of the bailer and replacement of the uphaul string. Groundwater samples collected during the second round of sampling were acid-preserved (HNO_3) for metals analyses and thiosulfate-preserved for organic priority pollutant and hydrocarbon analyses.

Groundwater samples were collected for microbiological counts according to the schedule indicated in Table 5. Sterile sampling methods and sterile sample containers were used.

C. PROBLEMS ENCOUNTERED

Due to varied site conditions, a number of problems arose during construction and startup of the system. The first significant problem arose during well construction. While flushing the drilling mud out of Well I-2, muddy water began to flow out of completed Wells P-4 and P-5. These wells required redevelopment. This occurrence suggested the presence of underground channeling in that area of the site. However, results of testing to date do not show any significant acceleration of breakthrough in these wells compared to other wells in the demonstration area.

Pumping rates from most of the wells are less than originally anticipated. These low pumping rates have created a problem with the temperature of the groundwater in the pumping wells. Due to the small volume of groundwater which is actually removed from the well, the temperature of the water continually increases due to the heat generated by the pump. As a result, the groundwater temperature in some wells temporarily reached as high as 100°F. This problem was controlled by cycling the pumping operation. Alternate pumps are operated and then turned off for equal periods of time.

In addition to the low pumping rates, injection rates were also found to be much lower than expected. Several of the wells temporarily overflowed and the rates had to be reduced. This created a situation in which more water was being pumped into the surge tank than could be injected into the injection wells. To solve this problem and the problem of elevated water temperature, the pumping operation was switching to a cycling mode. Alternate pumps are operated for a given time period and then shut off for an equal period. This reduces the total flow into the surge tank and allows the pumps a period of downtime which controls the temperature of the water in the well.

After several days of nutrient addition, a significant drop in the injection rate was noticed. A thick, white precipitate was also observed in the distribution box. Jar tests were performed to determine if nutrient precipitation was occurring which may have resulted in clogging of the well screens. Results from the jar tests showed that precipitation of nutrients in the distribution box could be eliminated by increasing the concentration of nutrients added to the groundwater. This was attributed to chelating agents present in the nutrient solution. Nutrient addition was also switched to a batch mode over a 3-hour period, rather than continuous addition during system operation, in order to maintain the overall nutrient loading. These changes in the initial design of system operation eliminated any precipitation in the distribution box. However, injection rates did not substantially increase. The injection wells were then manually cleaned using a large diameter pipe brush. This removed a large amount of precipitate from each of the wells and resulted in increased injection rates. However, there is still some concern due to precipitation that may have occurred within the formation itself, causing clogging of pore spaces. Such clogging may be detrimental to the continued successful performance of the demonstration.

SECTION V

RESULTS TO DATE

A. CHEMICAL AND MICROBIOLOGICAL DATA

The intent of the field demonstration is to show whether organic contaminants present at the site will degrade due to the action of indigenous microbes stimulated with the addition of oxygen and nutrients. To this end, soil samples were collected from the demonstration site between 22 April 1985 and 30 April 1985 during well construction. Groundwater samples were collected 23 May 1985 following well development and construction of the treatment system. The samples were analyzed to determine baseline values of contaminants present at the demonstration site. All raw data from analyses performed on soil and groundwater samples are included in the text or Appendix H.

1. Results of Soil Chemical Analyses

Results from oil and grease extractions on solids for quantification of hydrocarbons are shown in Table 6. Oil and grease concentrations ranged from 140 ppm to 535 ppm. Well P-1, sampled at 22 feet below ground surface, contained the highest concentration of oil and grease, present at 535 ppm. All other soil samples contained 140 ppm to 195 ppm oil and grease. No definite correlation between concentration and sample depth was evident.

The method used to determine total hydrocarbon concentrations on samples collected initially was an oil and grease extraction. The method quantifies all hydrocarbon compounds present in the sample matrix, including straight chain hydrocarbons, high molecular weight fatty acids, oils, esters, waxes, fuels, greases, and animal fats. It was determined, following initial analyses, that a more suitable analytical method would be required

TABLE 6. RESULTS OF SOIL OIL AND GREASE/
TOTAL HYDROCARBON ANALYSES

Sampling Date	Log No.	Sample Description	Total Hydrocarbons (ppm and %)
04/22/85	17633	P-1 22'	535 (0.05%)
04/23/85	17631	P-1 27'	195 (0.02%)
04/24/85	17635	P-3 21'	180 (0.02%)
04/24/85	17639	P-3 28'	185 (0.02%)
04/29/85	17632	I-2 20'	195 (0.02%)
04/30/85	17636	I-2 28'	190 (0.02%)
04/26/85	17637	I-3 25'	165 (0.01%)
04/27/85	17630	I-3 30'	140 (0.01%)
04/24/85	17634	I-4 25'	190 (0.02%)
04/26/85	17638	I-4 30'	140 (0.01%)

which selectively quantified lower molecular weight hydrocarbon compounds. All subsequent hydrocarbon analyses were performed by GC/FID.

Soil samples collected between 30 July and 8 August 1985 were analyzed for total hydrocarbons using gas chromatography. This analysis quantified lower molecular weight hydrocarbons which are more suitable substrates for microbial metabolism than those quantified by oil and grease analysis. The results are given in Table 7. A soil sample was collected between I-4 and P-8 and designated SB-3. This sample (SB-3) contained 0.071 ppm total hydrocarbons. Analyses of the remaining soil samples resulted in nondetectable quantities of total hydrocarbons.

It should be noted that direct comparison cannot be made between total hydrocarbons from oil and grease analysis and total hydrocarbons from GC analysis because different analytical methods were utilized. Oil and grease analyses quantify a larger category of organic compounds present in the soil, and therefore, concentrations should be higher than those resulting from GC/FID analyses.

Results from the second round of soil samples indicate that the subsurface areas sampled do not contain high quantities of hydrocarbon compounds analyzed by either method. However, due to the heterogeneous nature of the demonstration site, pockets of hydrocarbon contaminants probably exist, but were not detected in the second round of sampling.

Priority pollutant analyses of soils collected 22 April through 30 April 1985, indicated that no volatile, acid extractable, base/neutral extractable, or pesticide/PCB compounds were present in concentrations greater than the detection limits. However, the detection limits specified for the initial soil samples (generally 1 ppm), were higher than those normally specified by most analytical laboratories.

TABLE 7. RESULTS OF SOIL GC/TOTAL HYDROCARBON ANALYSES

Sampling Date	Log No.	Sample Location	Total Hydrocarbons mg/kg (ppm)
07/30/85	SB-1	I-2[a] 25'-27'	ND
08/03/85	SB-2	I-3[a] 25'-27'	ND
08/02/85	SB-3	I-4[a] 25'-27'	0.071
08/02/85	SB-4	P-9[a] 25'-27'	ND

ND = None detected

[a] Samples were taken from location nearest well indicated, at depth specified.

Chemical analysis on the soil samples collected from 30 July through 8 August 1985 were generally performed to lower detection limits than chemical analysis for the April samples. The soil samples were analyzed for organic priority pollutants and the results indicated the presence of methylene chloride and bis (2-ethylhexyl) phthalate in the soil samples. Methylene chloride and bis (2-ethylhexyl) phthalate are common artifacts of laboratory procedures and may not, in fact, be present at the Kelly site.

Results of inorganic priority pollutant analyses of initial soil samples are given in Table 8. Metals present in concentrations greater than 10 ppm were antimony, chromium, lead, nickel, silver, thallium, and zinc. Arsenic, cadmium, and copper were present in soil samples at values ranging from 1 to 10 ppm. No significant concentrations of beryllium, mercury, or selenium were present in the soil. Concentrations of arsenic, cadmium, copper, lead, nickel, silver, and thallium were present in fairly constant concentrations throughout the demonstration site. Antimony concentrations ranged from 70.7 ppm to 249 ppm, chromium ranged from 9.34 ppm to 233 ppm, and zinc concentrations varied from 24.9 ppm to 249 ppm.

Similar concentrations of metals were found in soil samples used to construct the microcosms for the biodegradation treatability study. Concentrations of metals found in the microcosm soils and groundwater are presented in Table 3. It was concluded from the biodegradation treatability study that metal concentrations did not produce adverse effects on microbial degradation of organic compounds. Of concern was the potential for mobilization of metals due to nutrient and hydrogen peroxide addition.

Inorganic priority pollutant analyses from the second soil sampling effort (30 July through 8 August 1985) are also given in Table 8. Metals present in concentrations greater than 10 ppm were chromium, copper, nickel, and zinc. Arsenic, beryllium, and silver were present in a few soil samples

TABLE 8. RESULTS OF SOIL INORGANIC ANALYSES

Sampling Date	Log No.	Sample Description	Total-P	Ortho-PO$_4$	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn
04/22/85	17633	P-1 22'	76.4	31.2	249	2.76	<0.5	9.30	56.6	6.54	88.2	0.09	27.2	<0.05	12.4	59.2	25.0
04/23/85	17631	P-1 27'	416	94.6	199	4.12	<0.5	8.53	33.5	6.86	76.5	<0.05	28.2	<0.05	11.9	54.8	36.1
04/24/85	17635	P-3 21'	404	41.1	209	6.25	<0.5	6.58	107	6.68	56.5	<0.05	21.6	<0.05	7.92	38.2	21.3
04/24/85	17639	P-3 28'	2937	32.2	70.7	4.46	<0.5	1.85	98.6	5.58	30.3	<0.05	18.5	<0.05	5.06	28.8	116
04/29/85	17632	I-2 20'	266	43.0	124	2.39	<0.5	5.67	9.34	5.77	60.8	<0.05	17.3	<0.05	6.78	25.1	24.9
04/30/85	17636	I-2 28'	6265	<2.0	231	5.20	<0.5	7.12	160	6.21	60.7	<0.05	33.3	<0.05	9.79	39.8	102
04/26/85	17637	I-3 25'	4027	2.92	175	3.39	<0.5	4.16	124	5.91	54.9	<0.05	31.9	0.66	4.43	34.3	107
04/27/85	17630	I-3 30'	5386	<2.0	192	5.11	<0.5	2.39	233	6.95	42.9	<0.05	25.9	0.39	13.6	25.9	249
04/24/85	17634	I-4 25'	4652	<2.0	155	5.32	<0.5	2.66	213	6.39	53.8	<0.05	24.1	<0.05	8.11	24.7	115
04/26/85	17638	I-4 30'	4802	49.5	92.7	4.47	<0.5	2.56	129	6.03	38.7	<0.05	19.4	<0.05	5.79	31.8	106
07/30/85	SB-1	I-2[a]25'-27'	5700	24	ND	ND	<2.0	ND	180	4.5	ND	ND	<10	ND	ND	<20	48
08/03/85	SB-2	I-3[a]25'-27'	3500	34	ND	1.1	<2.0	0.08	150	<4.0	ND	<0.1	14	ND	4.0	<20	60
08/02/85	SB-3	I-4[a]25'-27'	4500	120	<50	1.0	2.0	ND	380	5.9	ND	<0.1	<10	<0.2	ND	<20	47
08/02/85	SB-4	P-9[a]25'-27'	290	0.4	ND	4.9	ND	ND	880	15	ND	0.21	13	ND	ND	<20	23

Results expressed in µg/g (ppm)
ND = None detected
[a] Samples were taken from location nearest well indicated, at depth specified.

at values ranging from 1 to 10 ppm. No significant concentrations of antimony, cadmium, lead, selenium, or thallium were present in the soil.

Significant changes in several metal ions occurred between the initial and second sampling rounds. Antimony concentrations taken from I-2 during well drilling were 124 ppm at 20 feet sampling depth and 231 ppm at 28 feet sampling depth. The soil sample collected 30 July 1985 was taken from a location between I-2 and P-3, 4.4 feet from I-2, at a sampling interval of 25 feet to 27 feet below ground surface. Analysis of the sample detected no antimony present at the method detection limit. Well I-3 was sampled during drilling and the soil analyses resulted in 175 ppm antimony present at 25 feet and 192 ppm antimony present at 30 feet. No antimony was detected in a soil sample collected 3 August 1985, at a location between I-3 and P-5, approximately 6.0 feet from I-3. Analysis of I-4 soil sample resulted in 155 ppm antimony initially at 25 feet and 92.7 ppm antimony initially at 30 feet. Less than 50 ppm antimony were detected in a soil sample collected 2 August 1985 from an area located between I-4 and P-8, approximately 4 feet from I-4. These results are given in Table 8, and suggest that mobilization of antimony may be occurring in the subsurface. The mobilization of antimony was suggested as a potential problem following the laboratory biodegradation study when results indicated that antimony concentrations in the soil had decreased following 49 days of treatment with hydrogen peroxide.

Other metal ions which showed decreases in concentrations during the demonstration period included cadmium, lead, silver, thallium, and zinc. Lead concentrations appeared to decrease significantly during the treatment period. Initial concentrations present in the soil at Well I-2 were 60.8 ppm and 60.7 ppm, sampled at depths of 20 feet and 28 feet,respectively. Well I-3 contained 54.9 ppm lead at 25 feet and 42.9 ppm lead at 30 feet when sampled during drilling. Well I-4 contained 53.8 ppm at 25 feet and 38.7 ppm at 30 feet prior to treatment. All soil samples collected subsequently contained nondetectable quantities of lead. These results also suggest possible mobilization of lead in the subsurface.

Decreases in cadmium, silver, thallium, and zinc concentrations during the demonstration period were not as large as those observed for antimony and lead, although some mobilization due to peroxide-induced oxidation/reduction reactions may have occurred.

Total phosphorus and inorganic orthophosphate data are presented in Table 8. Total phosphorus concentrations in the soil sampled during well drilling ranged from 76.4 g/g (ppm) to 6265 g/g. Total phosphorus concentrations increased with sampling depth for each borehole sampled. Inorganic orthophosphate concentrations ranged from less than 2.0 g/g to 94.6 g/g. No correlation was apparent between orthophosphate concentrations and sample depth.

Phosphorus is present in the environment as inorganic orthophosphates and polyphosphates, and organic phosphorus. In soils, organic phosphorus is reduced by bacteria to inorganic phosphates. Phosphorus can be immobilized as an unavailable chemical compound. Of primary concern at the Kelly site was precipitation of insoluble phosphate compounds resulting in clogging of the pore spaces and reduced permeability in the subsurface. In acidic soils, the solid phase phosphate is generally associated with iron or aluminum cations while calcium phosphate precipitates occur more often in basic soils. Chemical analyses performed in the field, on soil samples, indicate low (nondetectable) quantities of iron, and high (200-300 ppm) concentrations of calcium. These results are given in Table 9. Therefore, an adequate concentration of calcium ions are present in the soil to form insoluble calcium phosphate precipitates. Nutrients were supplied in the form of potassium salts. However, the ortho- and polyphosphates present in the nutrient solution could form precipitates with the calcium present in the soil, resulting in decreased permeability and low injection rates.

TABLE 9. RESULTS OF SOIL FIELD TEST ANALYSES

Sampling Date	Sample Location	pH	Ca	Fe	Mg	Mn	NH_4	NO_3	NO_2	P	SO_4
04/22/85	P-1 22'	9.0	>200	ND	4	ND	2	10	ND	0.5	ND
04/24/85	P-3 21'	9.0	>200	ND	4	ND	2	10	ND	0.5	ND
04/24/85	P-3 28'	9.0	>200	ND	6	ND	2	10	ND	0.5	ND
04/29/85	I-2 20'	9.0	>200	ND	6	ND	ND	2	ND	0.5	ND
04/30/85	I-2 28'	9.0	>200	ND	6	ND	ND	2	ND	0.5	ND
04/26/85	I-3 25'	9.0	>200	ND	4	ND	ND	ND	ND	0.5	ND
04/27/85	I-3 30'	9.0	>200	ND	4	ND	ND	ND	ND	0.5	ND
04/24/85	I-4 25'	9.0	>200	ND	4	ND	2	25	ND	0.5	ND
04/26/85	I-4 30'	9.0	>200	ND	4	ND	2	25	ND	0.5	ND
07/30/85	I-2[a]25'	7.0	300	ND	6	ND	ND	ND	ND	0.5	ND
08/03/85	I-3[a]25'	7.0	300	ND	6	ND	ND	ND	ND	0.5	ND
08/02/85	I-4[a]25'	7.0	300	ND	6	ND	ND	ND	ND	0.5	ND
08/02/85	P-9[a]25'	7.0	300	ND	6	ND	<2	<2	ND	0.5	ND

Results expressed in ppm
ND = None detected
[a] Samples were taken from location nearest well indicated, at depth specified.

Total phosphorus and inorganic orthophosphate concentrations are also presented in Table 8 for the soil samples collected following approximately 2 months of nutrient addition. No significant differences were noted in total phosphorus content of the soil caused by the treatment method. However, orthophosphate concentrations were consistently higher in soil samples collected following treatment. Addition of nutrients in the form of orthophosphates resulted in an increase in the concentration of orthophosphate observed.

Additional chemical analyses were performed on soil samples using field test kits. These results are summarized in Table 9. All initial pH values of the soil samples were equal to pH 9.0. Calcium concentrations were detected in concentrations greater than 200 ppm. Soil samples taken from Well I-4 contained 25 ppm nitrate (NO_3). All other cationic and anionic species were present in concentrations equal to or less than 10 ppm.

Field analyses conducted on soil samples collected following 2 months of nutrient addition indicated the pH of the soil had decreased to pH equal to 7.[illegible]. Calcium concentrations were detected in the soil samples at levels equal to 300 ppm. Nitrate (NO_3) concentrations present adjacent to Well I-4 decreased from 25 ppm to values below the detection limit. Phosphorus concentrations detected in all soil samples using the soil test kit, were equal to 0.5 ppm. The field kit measures soluble phosphorus, in comparison to laboratory chemical analyses, which quantifies total soil phosphorus. These results are summarized in Table 9. The remaining parameters did not show significant changes from initial values detected.

Reductions in soil pH can be attributed to the addition of nutrients and hydrogen peroxide. The buffering capacity of the nutrient solution (pH 6.8) will, however, stabilize the soil at a neutral pH. Nitrate anions are retained weakly and are rather mobile in soils. Nitrate is also actively taken up and reduced by soil organisms. Denitrification or mobilization of nitrate anions could easily have occurred in the area of I-4 due to the higher relative permeability of this zone.

2. Results of Groundwater Chemical Analyses

Results of initial groundwater sample analyses for organic priority pollutants are found in Table 10. Priority pollutants present in the groundwater at levels greater than 1.0 ppm included tetrachloroethylene (PCE), trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-1,2-DCE), and 1,1-dichloroethane (1,1-DCA). Other priority pollutants found at levels ranging from 0.1-1.0 ppm included 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethylene (1,1-DCE), and vinyl chloride. Groundwater samples were collected from four wells on 8 August 1985. These results are presented in Table 11. Contaminants present in concentrations greater than 1.0 ppm included DCE, TCE, and trans-1,2,-dichloroethylene (trans-1,2-DCE). Other organic priority pollutants present in concentrations ranging from 0.1-1.0 ppm included 1,1,1-TCA, 1,1-DCE, 1,1-DCA, and vinyl chloride. Chloroethane and chlorobenzene were present in concentrations less than 0.1 ppm. Due to a change in the analytical laboratory used for chemical analyses and the availability of only two data points, no definite conclusions can be stated at this time concerning degradation of organic compounds. Replicate and field blank data is also presented in Table 11. No priority pollutant compounds were detected in the field blank.

Oil and grease extractions for total hydrocarbons were performed on initial groundwater samples collected from the site. These results are given in Table 12. All groundwater samples contained concentrations less than 5 ppm. Wells I-4 and M-2 contained 3 ppm oil and grease hydrocarbons, while Wells P-2, P-4, and P-6 contained 2 ppm oil and grease hydrocarbons. All remaining wells (P-1, P-3, P-5, P-7, P-8, P-9, I-1, I-2, I-3, M-1) were sampled and found to contain 1 ppm or less oil and grease.

Groundwater samples collected 8 August 1985 from 10 wells, were

TABLE 10. RESULTS OF GROUNDWATER ORGANIC PRIORITY POLLUTANT ANALYSES

	P-1	P-2	P-4	P-6	P-8	P-9
Tetrachloroethylene	0.0081	0.70	2.30	0.50	2.90	3.65
Trichloroethylene	0.0248	2.65	1.65	1.10	3.00	5.05
1,1,1-Trichloroethane	--	--	0.001	--	0.60	--
1,1,2-Trichloroethane	--	--	--	--	0.0047	--
Trans-1,2-Dichloroethylene	0.0289	0.0944	--	--	0.0216	0.0142
Cis-1,2-Dichloroethylene	2.35	2.80	1.10	8.50	2.35	5.10
1,1-Dichloroethylene	--	0.0346	0.004	--	--	0.147
1,1-Dichloroethane	0.0291	0.0577	0.0034	0.0185	1.15	--
1,2-Dichloroethane	0.0019	0.0031	0.0013	0.0024	0.0057	--
Vinyl Chloride	0.753	0.0525	--	0.499	0.239	0.0231
Chloroethane	--	--	--	--	0.0354	--
Chloroform	--	--	--	--	--	0.0118
Benzene	--	--	--	--	--	0.002
Chlorobenzene	0.0063	0.0411	0.0089	0.0166	0.0528	0.0025
Toluene	--	0.0028	0.0041	0.0015	0.002	0.0019

Note: -- indicates none detected
Results expressed in mg/l (ppm)
Samples collected 23 May 1985

TABLE 11. RESULTS OF GROUNDWATER ORGANIC PRIORITY POLLUTANT ANALYSES

	P-1	P-4	P-8	P-9	P-9 Replicate	Field Blank
Tetrachloroethylene	0.630	4.00	0.290	2.00	2.90	--
Trichloroethylene	0.660	2.60	0.710	2.00	3.70	--
1,1,1-Trichloroethane	--	--	0.440	--	--	--
Trans 1,2-Dichloroethylene	3.70	0.950	1.10	3.60	3.90	--
1,1-Dichloroethylene	--	--	0.220	0.015	0.017	--
1,1-Dichloroethane	--	--	0.700	0.021	--	--
Vinyl Chloride	0.340	--	0.360	0.520	0.600	--
Chloroethane	--	--	0.021	--	--	--
Chlorobenzene	--	--	0.060	0.035	0.040	--

Note: -- indicates none detected
Results expressed in mg/l (ppm)
Samples collected 8 August 1985

TABLE 12. RESULTS OF GROUNDWATER OIL AND GREASE TOTAL HYDROCARBON ANALYSES

Log No.	Sample Location	Total Hydrocarbons (mg/l or ppm)
18100	P-1	1
18101	P-2	2
18102	P-3	<1
18103	P-4	2
18104	P-5	<1
18105	P-6	2
18106	P-7	<1
18107	P-8	1
18108	P-9	1
18094	I-1	<1
18095	I-2	<1
18096	I-3	1
18097	I-4	3
18098	M-1	<1
18099	M-2	3

Samples collected 23 May 1985

analyzed for total hydrocarbons using GC/FID method. The results are given in Table 13. Although direct correlation can not be made between oil and grease hydrocarbon analyses and GC hydrocarbon analyses, the previous method will detect a larger category of compounds than the GC method. Of particular concern was the increased concentrations of hydrocarbons detected in Wells P-4, I-3, I-4, and monitoring Well M-2. These data suggests the potential migration of petroleum-based hydrocarbons within the treatment zone, although conclusive data are not available and possible reasons for this occurrence are not known at this time.

Inorganic priority pollutant analyses were performed initially on groundwater samples and the results are given in Table 14. All metals were detected at levels less than 1.0 ppm. Antimony, beryllium, cadmium, and thallium were not detected at levels greater than method detection limits in any of the wells sampled. Chromium was present in Well P-4 at a concentration equal to 0.084 ppm. Copper concentrations varied from less than 0.001 ppm to 0.406 ppm and lead values ranged from less than 0.01 ppm to 0.54 ppm. Nickel concentrations were found at levels between 0.04 ppm and 0.24 ppm and zinc was detected from 0.083 ppm to 0.264 ppm.

Similar inorganic concentrations were detected in groundwater samples used for the treatability study biodegradation microcosms. As discussed above, metal concentrations did not appear to adversely affect microbial degradation of the contaminants present.

Results from inorganic priority pollutant analyses conducted on the second round of groundwater samples showed similar concentrations of metals. All metals were detected at levels less than or equal to 1.0 ppm. Antimony, beryllium, and mercury were not detected at levels greater than method detection limits in any of the wells sampled. Replicate and field blank analyses showed acceptable results. No increases in metal ions, particularly antimony and lead, were detected in the groundwater samples. Therefore, if mobilization of these metal ions is occurring, as may be suggested by

TABLE 13. RESULTS OF GROUNDWATER GC/ TOTAL HYDROCARBON ANALYSES

Log No.	Sample Location	Total Hydrocarbons (mg/l or ppm)
P-1	P-1	ND
P-2	P-2	ND
P-4	P-4	6.80
P-6	P-6	ND
P-8	P-8	ND
P-9	P-9	0.580
I-1	I-1	0.150
I-3	I-3	1.40
I-4	I-4	730
M-2	M-2	4700

Samples collected 8 August 1985
ND = none detected

TABLE 14. RESULTS OF GROUNDWATER INORGANIC ANALYSES

Sampling Date	Log No.	Sample Description	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn
05/23/85	18100	P-1	<0.01	<0.001	<0.01	<0.01	<0.001	0.131	0.35	<0.0001	0.17	<0.001	<0.001	<0.01	0.264
05/23/85	18101	P-2	<0.01	0.003	<0.01	<0.01	<0.001	0.406	0.54	<0.0001	0.24	<0.001	0.090	<0.01	0.239
05/23/85	18103	P-4	<0.01	0.006	<0.01	<0.01	0.084	0.114	0.34	0.0005	0.04	0.004	<0.001	<0.01	0.259
05/23/85	18105	P-6	<0.01	0.004	<0.01	<0.01	<0.001	0.098	0.41	<0.0001	0.08	<0.001	<0.001	<0.01	0.117
05/23/85	18107	P-8	<0.01	0.005	<0.01	<0.01	<0.001	0.178	<0.01	<0.0001	0.12	<0.001	<0.001	<0.01	0.108
05/23/85	18108	P-9	<0.01	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	0.0002	0.04	<0.001	<0.001	<0.01	0.083
08/08/85	P-1	P-1	ND	ND	<0.005	<0.01	<0.02	0.32	<0.05	<0.0002	<0.05	0.001	ND	<0.01	1.0
08/08/85	P-4	P-4	ND	<0.001	ND	ND	0.10	0.03	ND	<0.0002	<0.05	<0.001	ND	ND	<0.02
08/08/85	P-8	P-8	ND	0.033	ND	ND	ND	0.04	<0.05	ND	ND	0.015	<0.02	<0.10	ND
08/08/85	P-9	P-9	ND	0.050	ND	<0.01	<0.02	0.07	ND	ND	ND	0.005	ND	ND	ND
08/08/85	P-9(R)	P-9(Replicate)	ND	0.050	ND	<0.01	<0.02	0.06	ND	ND	<0.05	0.019	<0.02	<0.10	ND
08/08/85	FB	Field Blank	ND	ND	ND	<0.01	ND	<0.02	ND	ND	<0.05	ND	<0.02	<0.10	ND

Results expressed in mg/l (ppm)
ND = None detected

decreased concentrations detected in the soil samples, the concentrations have not increased to a level high enough in the groundwater to be detected.

General groundwater quality and process performance was monitored routinely throughout the treatment project. These results are detailed in Appendix H.

Routine temperature readings reflect the temporary increase in groundwater temperature generated by recirculating water in the pumping wells. One result of the increased groundwater temperatures was an apparent decrease in microbial populations.

The dissolved oxygen concentration appeared to increase in Well P-2, following the initiation of hydrogen peroxide treatment. However, subsequent dissolved oxygen readings recorded for Well P-2 decreased to values close to the initial level detected in the groundwater. The dissolved oxygen levels for all other pumping wells remained fairly constant throughout the duration of the demonstration project. In addition, it should be noted that recirculation of water in the pumping wells will affect the dissolved oxygen levels in the groundwater sampled from these wells. Therefore, dissolved oxygen levels in the aquifer may be lower than those indicated by the pumping well data. Dissolved oxygen levels increased in the injection wells following the addition of hydrogen peroxide due to the decomposition of hydrogen peroxide to oxygen and water.

Conductivity values for each well sample were taken during the demonstration project. Conductivity values reflect the amount of dissolved solids present in the water sample tested. Increases in conductivity values noted for the injection wells were due to nutrient and peroxide additions. The increase in conductivity values recorded in Wells P-9 and M-2 suggest transport of nutrients to those areas of the treatment zone. Slug tests performed on each pumping well indicated a relatively high hydraulic conductivity in the region of Well P-9. Therefore, transport of nutrients through this area may be expected.

Groundwater sampled from each injection, pumping, and monitoring well was routinely analyzed for pH. Values recorded for pH remained fairly constant throughout the demonstration project.

Ammonia-nitrogen (NH_3) is added to the groundwater as the nitrogen source supplied to the microbial population. High concentrations of NH_3 were detected in each injection well and remained fairly constant following addition of the nutrient solution (Restore® 375K) which began 7 June 1985. A significant increase in NH_3 concentration with time was observed in Well P-9. These results indicate transport of nutrients to this area of the treatment zone. Slight increases in ammonia concentrations with time were also observed for Wells P-1, P-3, and P-8, indicating that breakthrough of nutrients is likely to occur in these areas.

Phosphate (PO_4) concentrations monitored during the demonstration project showed similar trends as ammonia concentrations. PO_4 is added as a microbial nutrient in the form of Restore® 375K. High concentrations were detected in the injection wells due to nutrient addition. PO_4 concentrations increased with time, in groundwater sampled from Wells P-8 and P-9. Breakthrough of PO_4 was more rapid in P-9 indicating an area of more rapid nutrient transport through the formation.

Chloride was also added in the nutrient solution, Restore® 375K. Increased concentrations of chloride ions were detected with time in each of the injection wells and in all pumping wells. Slight increases in chloride concentrations were also detected in the monitoring Wells, M-1 and M-2. These results suggest that transport of chlorides is occurring in all areas of the treatment zone. In addition, some transport of the nutrient solution may be occurring to areas outside the treatment zone. Additional monitoring will determine whether nutrients are, in fact, being transported outside the treatment zone. The concentrations of chlorides detected in Wells P-1 through P-8 increased much more slowly than the breakthrough observed in Well P-9.

Hydrogen peroxide (H_2O_2) levels were monitored during the demonstration period. High concentrations of H_2O_2 were detected in the injection wells after H_2O_2 addition was started. No breakthrough of H_2O_2 has occurred in any of the pumping wells or monitoring wells, as of 8 August 1985. These results suggest that H_2O_2 decomposition is occurring within the formation.

No significant increases of alkalinity, acidity, and hardness occurred in the pumping or monitoring wells. High concentrations were detected in the injection wells, due to the addition of nutrient and peroxide solutions.

Nitrate concentrations increased slightly with time in Wells P-4 and M-2. These results may be attributed to microbial or chemical reactions in the soil caused by nutrient or peroxide addition. All other chemical analyses for nitrate-nitrogen, sulfate, lead, and chromium remained constant throughout the treatment period.

3. Results of Biological Analysis

Enumeration of total bacterial and hydrocarbon-degrading bacteria was performed on groundwater and soil samples. Results which have been received to date are included in Appendix H. Total bacteria populations present in groundwater sampled prior to system start-up ranged from 0.4×10^5 cells/ml to 29×10^5 cells/ml. Groundwater samples were collected prior to nutrient addition and total bacteria populations ranged from 0.4×10^5 cells/ml to 31×10^5 cells/ml. Total hydrocarbon-degrading bacteria ranged from 0.07×10^5 cells/ml to 8.7×10^5 cells/ml in groundwater samples collected prior to system start-up and 0.03×10^5 cells/ml to 1.3×10^5 cells/ml prior to nutrient addition. These data indicate the presence of a healthy, adapted bacteria population. The range of microbial populations obtained from groundwater samples collected 2 weeks after nutrient addition was initiated and prior to H_2O_2 addition, was generally similar to the values obtained previously. Total bacteria present varied from 0.60×10^5 cells/ml to 38×10^5 cells/ml and hydrocarbon-degrading bacteria ranged from 0.002×10^5 cells/ml to 0.80×10^5 cells/ml. Individual wells had lower values which may have been due to the high temperature of the groundwater generated during recirculation in the pumping wells.

Groundwater sampling for microbial enumeration was continued at two week intervals, throughout the demonstration project. Groundwater samples collected during July indicated no significant changes in total microbial populations. However, hydrocarbon-degrading bacterial counts appeared to decrease slightly. This may be attributed to increased groundwater temperature due to pumping, the availability of an organic substrate, or a period of microbial population adaptation, which was required, due to hydrogen peroxide addition.

The hydrocarbon-degrading microbial population appeared to respond favorably during the next month of system operation, as indicated by the enumeration results from groundwater samples collected in August 1985 (see Appendix H). Hydrocarbon-degrading bacterial counts increased for each of the 9 pumping wells and total microbial counts remained constant or increased slightly in samples collected from the pumping wells during August 1985. These results confirm the presence of a highly adaptive bacterial population in the groundwater. Microbial populations in the injection wells remained low (0.001×10^5 cells/ml), however, indicating a slower response for both total and hydrocarbon-degrading bacteria, at the point of groundwater injection.

Soil microbial populations were determined on soil borings obtained during well installation. The total bacterial populations ranged from 4.3×10^4 cells/gm soil to 1.0×10^7 cells/gm soil. Total hydrocarbon-degrading bacteria ranged from 1.8 x 10^4 cells/gm soil to 1.1 x 10^7 cells/gm soil. There was no significant difference between total and hydrocarbon-degrading bacteria present in the soil. As with the groundwater samples, these results indicate the presence of a healthy microbial population, well adapted for hydrocarbon degradation. The soil and groundwater microbial analyses also suggest that chemical compounds present in the subsurface are not inhibitory to the microbial population.

Soil samples were collected from 30 July to 3 August 1985 at locations adjacent to Wells I-2, I-3, I-4, and P-9. Total and hydrocarbon-degrading bacterial counts were performed. Total bacteria counts ranged from 4.0 x 10^4 cells/gm soil to 1.4 x 10^7 cells/gm soil, while hydrocarbon-degrading bacteria counts varied from 1.2 x 10^4 cells/gm to 1.4 x 10^6 cells/gm. No significant reduction in microbial activity was observed for the second set of soil microbial enumeration. Again, this verifies that a healthy population of bacteria exists in the soil and that chemical compounds present in the soil are not inhibitory to the microbial population.

4. Trends

General trends were observed as a result of the chemical and biological monitoring and are summarized below. Organic priority pollutants and total hydrocarbons were not detected in significant quantities in the soil samples to provide appreciable organic substrates for microbial metabolism. Significant quantities of biodegradable hydrocarbons and chlorinated organic compounds are present in the groundwater at various areas within the treatment zone. Biodegradation of the hydrocarbon compounds, chlorinated aliphatics, such as 1,1-DCE and 1,1-DCA, and chlorinated aromatics, such as chlorobenzene, can be expected based on results of the laboratory treatability study. However, chlorinated compounds such as PCE, TCE, and trans-1,2-DCE, which are present at the site in significant quantities, are not expected to degrade aerobically. As expected, no significant evidence of biodegradation has been observed following less than 2 months of hydrogen peroxide addition to the system.

Metal contaminants are present at significant levels in the soils but are not detected, or are quantified at very low levels, in the groundwater. Metal ions present in the soils are not detrimental to biological activity at the levels detected. Mobilization of antimony and lead from the soil may be occurring within the treatment zone. Other metal ion concentrations, including cadmium, silver, and zinc, have apparently decreased in the soil. Mobilization of metal ions may be attributed to peroxide induced oxidation/reduction reactions in the soil, but additional data is needed to support this theory. No increase of metal concentrations in groundwater have been detected.

One additional change in the chemical characteristic of the soil was a significant decrease in soil pH. This change was most likely due to the addition of hydrogen peroxide and nutrients to the subsurface. However, the buffering capacity of the nutrient solution should stabilize the soil at a neutral pH.

Nitrogen and phosphorus are being supplied in sufficient quantities to the subsurface to maintain the microbial population. The addition of nutrients and the presence of high concentrations of calcium ions in the soil resulted in a decrease in permeability in some areas of the treatment zone. This was evidenced by low injectivity rates noted during system operation.

General groundwater quality has not been adversely affected by the treatment method used. Alkalinity, acidity, hardness, nitrate-nitrogen, sulfate, lead, and chromium concentrations, and groundwater pH remained relatively constant in the recovery wells.

Breakthrough of chloride ions has been detected throughout the treatment zone while breakthrough of nutrients (ammonia and phosphates) has been detected in pumping Well P-9. Figure 12 shows the increases in ammonia, phosphate and chloride ions with time in Well P-9. The breakthrough curve shows that transport of nutrients has occurred through this area of the demonstration site. Increases in conductivity may indicate transport of nutrients downgradient of the treatment area in monitoring Well M-2. M-2 is also located in the direction of the more permeable areas at pumping Wells P-8 and P-9.

Microbial populations are present in adequate numbers to accomplish biodegradation of organic compounds. The data collected to date suggest that a well adapted population of microbes exist throughout the demonstration site.

Treatment effectiveness is most likely inhibited by the high degree of variability of organic substrate concentrations within the treatment zone. The heterogeneous nature of the subsurface environment is also a limiting factor for total site remediation although some zones of the site are hydrogeologically suitable for successful treatment of the contaminants.

B. COSTS

1. Costs at Kelly AFB

This section presents the costs associated with the construction and operation of the demonstration of *in situ* biological degradation at Kelly AFB. These costs are broken down into major components and presented in Table 15. These costs cover the period beginning 15 April 1985 and ending 30 September 1985. It is important to note that the costs of construction are actually very low (less than 20 percent of total costs including labor).

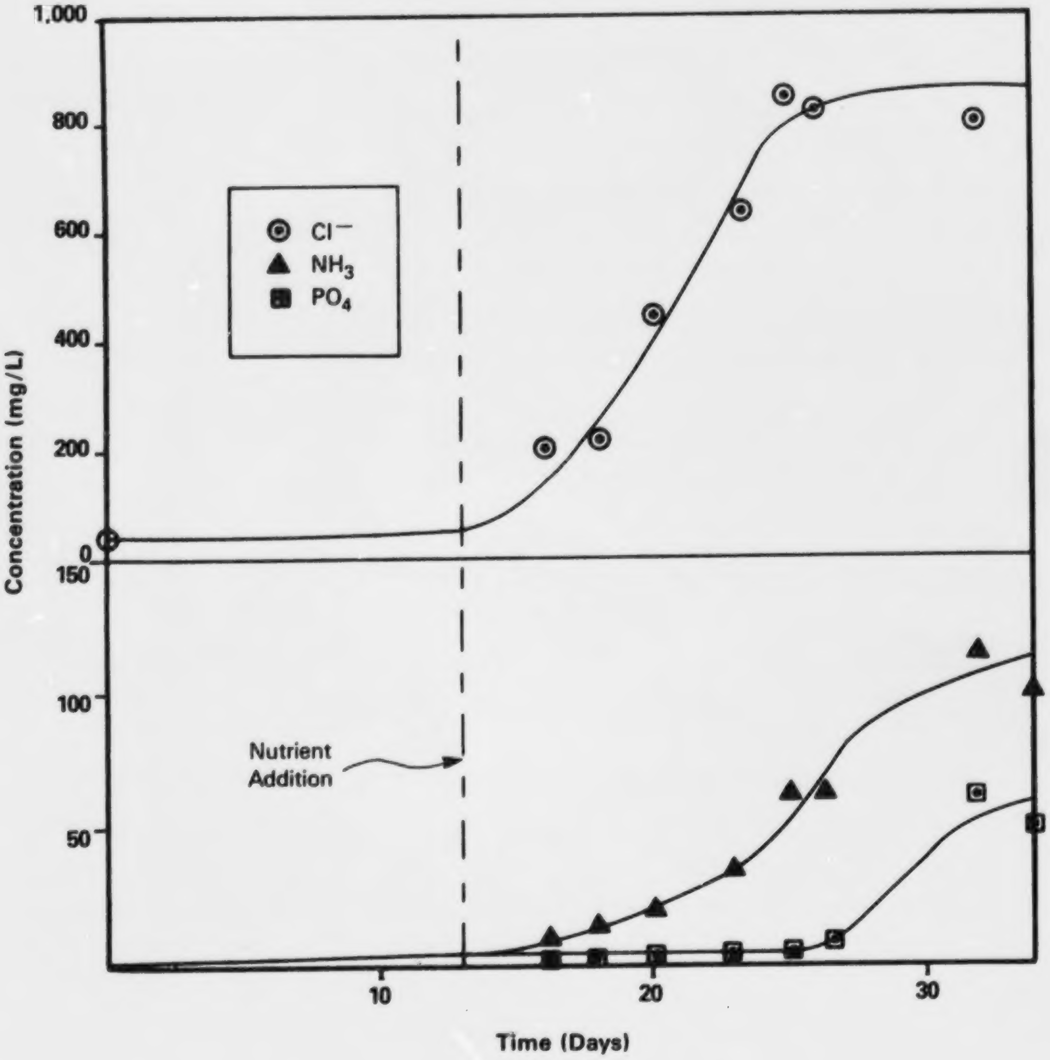

Figure 12. Nutrient Breakthrough Curve of NH_3, PO_4, and Cl for Pumping Well P-9

TABLE 15. BREAKDOWN OF COSTS FOR KELLY AFB DEMONSTRATION

Well Construction (13 30 ft wells)	
Materials and equipment	$11,600
Labor (Subcontract and SAIC)	$24,250
Construction of Recirculation System (Piping, tanks, pumps, etc.)	
Materials and equipment	$11,800
Labor	$4,900
Sampling and Analysis (15 wells for 3 months)	
Analytical fees	$41,570
Microbiological and onsite assistance	$39,550
Sampling and monitoring, materials and equipment	$5,850
Borehole sampling	
Materials and equipment	$200
Labor (Subcontract and SAIC)	$1,880
Chemicals (Nutrients and hydrogen peroxide for 3 months)	$2,850
Other Direct costs and Travel	$42,900
Labor Costs (Non-construction)	$94,500
TOTAL COSTS	$281,850

2. Costs of Bioreclamation at Other Sites

Detailed cost information for bioreclamation projects is generally not available in the literature. Of the several documented cases, costs are available from only one. An estimated 30,000 gallons of waste solvent leaked from underground tanks at Biocraft Laboratories in Waldwick, NJ, between 1972 and 1975. It was estimated that approximately 12,000 cubic yards of soil were contaminated in a 1.75-acre area to a depth of no more than 12 feet. A biological reactor system was installed and consisted of a downgradient dewatering trench and dewatering well system, two mobile biological activating tanks, two mobile settling tanks, and two upgradient reinjection trenches. Contaminated groundwater was pumped into the reactor where biodegradation rates were significantly increased by supplying air and nutrients. Sludge was settled from the treated water in the settling tanks and reintroduced to the activating tanks. Renovated water was discharged to the reinjection trenches. Groundwater was treated at the rate of 14,000 to 20,000 gallons per day with a median contaminant reduction of 60 percent per pass. The site operators estimated that approximately 40 percent of the biodegradation of wastes occurred in the deposit itself as a result of reinjection of bioactive (microbes and nutrient-supplemented) water (Reference 18).

The project was implemented in 1981 at a total capital cost of $925,678. Of the total, less than half ($405,150) was incurred during actual construction. The remainder was spent on the remedial investigation ($73,948) and the 2.5 year feasibility study ($446,580). Total daily operating costs averaged $272.90 or $100,000 per year. As of this writing, the system is still in operation.

3. Costs of Comparable Techniques

This section presents rough estimates for providing remedial action for the entire site area at Kelly AFB using four different technologies:

(1) in situ biodegradation, (2) pump-and-treat using granular activated carbon, (3) removal, and (4) containment using a slurry wall. Each of these estimates are presented along with the assumptions used to determine them. The site area being studied includes the paved storage yard and the immediate surrounding area. This area measures approximately 250 feet by 300 feet or approximately 1.7 acres.

a. In Situ Biodegradation

The cost for treating the proposed site area is determined by scaling up the costs incurred in the field demonstration at Kelly AFB. We assume that wells can be spaced at 25 feet instead of 15 feet for the demonstration area. This assumption is based on zones within the demonstration site where permeability is highest, particularly in the area of Wells P-8 and P-9. A spacing of 25-feet would be adequate for zones with relatively higher permeability. However, there are zones in the demonstration area which have a much lower relative permeability, as indicated in Table 1, but these zones would probably not be treated adequately, even at a 15-foot spacing. In addition, migration of contamination from the site is more likely to occur in the more permeable zones, for which the treatment system is being designed.

The scaled-up cost of treatment is presented in Table 16. It was assumed that operation would be performed for a period of 1 year. Construction costs were estimated on a per-well basis. At the 25-foot spacing, a total of 120 wells would be needed for the full scale treatment system. Sampling and analytical costs were estimated using sampling cost data for the present system. The number of groundwater and soil samples estimated to provide a good characterization of the site are given in Table 16. The cost of nutrients and hydrogen peroxide was estimated according to the size of the proposed site (75,000 square feet compared to less than 3,000 square feet of the demonstration area). Other sampling and analysis costs would

TABLE 16. SCALE-UP OF COSTS FOR FULL SITE *IN SITU* TREATMENT AT KELLY AFB

Well Construction (120 30 ft wells)	
Materials and equipment	$110,000
Labor (Subcontract and SAIC)	$225,000
Construction of Recirculation System (Piping, tanks, pumps, etc.)	
Materials and equipment	$110,000
Labor	$50,000
Sampling and Analysis (60 wells, monthly hydrocarbon and quarterly priority pollutant analysis; 20 quarterly soil samples)	
Analytical fees	$450,000
Microbiological and on-site assistance	$100,000
Sampling and monitoring, materials and equipment	$20,000
Borehole sampling (20 holes, sampled quarterly)	
Materials and equipment	$4,000
Labor (Subcontract and SAIC)	$37,500
Chemicals (Nutrients and hydrogen peroxide for 12 months)	$300,000
Other Direct costs and Travel	$100,000
Labor Costs (Non-construction)	$225,000
TOTAL COSTS	$1,731,500

not scale up in direct proportion to the size of the site and were estimated using best professional judgement. Nonconstruction labor, travel, and other direct costs would not increase due to the increased size of the system and were scaled up according to the longer time period only.

b. Pump-and-Treat

Many of the costs of using a pump-and-treat technology would be identical to those of in situ treatment. Groundwater would be pumped from the ground, treated, and the clean effluent would be returned to the subsurface. Table 17 shows cost estimates for a pump-and-treat system at the Kelly site using the same well configuration as the in situ design. Rather than nutrient and peroxide addition, treatment would be performed using an aboveground granular activated carbon unit. The GAC unit used for this estimate would treat 70 gpm. The same sampling schedule as that used for in situ was included.

c. Removal

The cost of removing the contaminated material from the entire 1.7 acre area in question would be prohibitively expensive and highly impractical. Removal would only be performed for the concentrated sludge, an area of approximately 150 feet by 150 feet to a depth of about 15 feet. The total volume of removed material would therefore be approximately 12,500 cubic yards. Recent costs for removal and disposal of contaminated soils from another location at Kelly AFB were approximately $18 per cubic yard for excavation and loading, $55 per cubic yard for transportation and $138 per cubic yard for disposal costs. Contaminated materials were transported to a licensed hazardous waste disposal facility located approximately 150 miles from Kelly AFB. Using these cost figures, excavation and loading costs for removal of the total volume of material (12,500 cubic yards) would amount to $225,000. Transportation of the contaminated

TABLE 17. BREAKDOWN OF COSTS FOR PUMP-AND-TREAT ALTERNATIVE AT KELLY AFB USING GRANULAR ACTIVATED CARBON

Well Construction (120 30 ft wells)	
Materials and equipment	$110,000
Labor (Subcontract and SAIC)	$225,000
Construction of Recirculation System (Piping, tanks, pumps, etc.)	
Materials and equipment	$110,000
Labor	$50,000
Construction of Activated Carbon Unit[1]	$42,425
Sampling and Analysis (60 wells and GAC effluent, monthly hydrocarbon and quarterly priority pollutant analysis; 20 quarterly soil samples)	
Analytical fees	$450,000
Sampling and monitoring, materials and equipment	$20,000
Borehole sampling (20 holes, sampled quarterly)	
Materials and equipment	$4,000
Labor (Subcontract and SAIC)	$37,500
Operation and Maintenance Costs[1]	$4,800
Other Direct costs and Travel	$100,000
Labor Costs (Non-construction)	$225,000
TOTAL COSTS	$1,378,725

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[1] (Reference 3)

material would cost $687,500 and disposal costs would equal $1,725,000. Therefore, the total cost is estimated at $2,637,500. In addition, it is important to note that removal of only the material of concentrated contamination may not constitute a complete site remediation and other actions may still be needed for the remaining material with low levels of contamination. Therefore, costs for this alternative may be even higher.

d. Containment Using Slurry Walls

The total perimeter distance around the site is about 1100 feet. To construct a soil bentonite slurry wall to a depth of 35 feet surrounding the area would involve approximately 38,500 square feet of wall. A unit cost of $10 per square foot can be assumed for a 3-foot thick wall (Reference 3) making the cost about $385,000. A cement-bentonite slurry wall would cost over three times as much (Reference 3). Note that this estimate includes construction costs only.

The need for additional capping material would have to be evaluated to determine if the existing asphalt pavement covering a portion of the site is effective in preventing the infiltration of water into the site and to determine if capping is needed for the portion of the site not covered by the asphalt pavement.

In summary, the following can be concluded for remedial alternatives for the Kelly AFB site:

- Effectiveness of *in situ* biological degradation may prove to be greater than conventional techniques based on the final outcome of the demonstration of the technology at Kelly AFB.
- *In situ* biological treatment has the capability to completely degrade organic contaminants to nontoxic end products, while other technologies simply transfer the contaminants from one phase to another without complete destruction.
- Additional site-specific information is needed to more accurately

evaluate removal and containment alternatives and more accurate cost information for in situ treatment would be available following the completion of the demonstration.

- Full-scale application of in situ biological degradation may be cost-effective when compared to conventional techniques such as waste removal or a pump-and-treat technology using granular activated carbon; however, other alternatives such as containment may be more cost-effective than the full-scale application of in situ biological degradation.

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SECTION VI

CONCLUSIONS

Based on groundwater and soil monitoring conducted before September 1985, conclusions can not be reached as to whether the degradation of organic contaminants is occurring at this site. However, evidence of degradation was not expected because of the short time period (3 months) during which the system has been fully operational. Additionally, there have been only two complete rounds of sampling for the system (one before startup and one after); therefore, any decreases or increases in levels of contamination cannot be fully explained without additional supporting data. Differences in location of soil sampling points, for example, could explain large discrepancies between the first and second sampling rounds, given the heterogeneity of soils at the site.

Preliminary field investigations and lab permeability studies showed that the subsurface soils were generally gravelly clay loams of low permeability. Hydraulic conductivities varied from 0.11 ft/day to 9.26 ft/day, a range of almost two orders of magnitude. Due to the heterogeneous nature of the subsurface, nutrient transport was more rapid in some areas of the demonstration site. Results from groundwater monitoring indicated that transport occurred quite rapidly in the areas of high hydraulic conductivity, and degradation of organic contaminants would be possible in those areas.

The microbial population continues to thrive, in both the subsurface soils and groundwater. Temporary reductions in the microbial population may be attributed to increased groundwater temperatures due to pumping, the availability of an organic substrate, or a period of adaptation required by the microbial population due to implementation of the treatment system. These results show that microbial populations can be effectively stimulated in subsurface soils and groundwater containing a mixture of inorganic and organic contaminants.

Operational problems created by the low hydraulic conductivities at the demonstration site include declining injection rates, insufficient pumping rates to promote groundwater circulation, and noncontinuous operation of the pumping and injection system. Despite these operational problems, valuable information has been obtained with regard to the applicability of in situ biodegradation. Continued operation of the system will provide additional information on the capabilities and limitations of in situ biodegradation as a treatment alternative for contaminated soils and groundwater.

The purpose of this effort is to demonstrate the feasibility of in situ biodegradation. This report documents only the first part of that effort. By assuming the eventual success of the field demonstration, general conclusions can be made regarding the eventual usefulness of this technology and comparisons with other alternatives can be made for cleanup of the entire 1.7-acre site at Kelly AFB. These general conclusions follow.

A. COMPARISON OF IN SITU BIOLOGICAL DEGRADATION WITH OTHER TECHNOLOGIES

In situ biodegradation of contaminated soil and groundwater is based on the concept of stimulating the indigenous subsurface microbial population to decompose the contaminants of concern. Optimum conditions for bacterial growth are provided by injecting the subsurface with nutrients, maintaining neutral pH, and circulating the groundwater using a series of injection and pumping wells. A source of oxygen is required for aerobic biodegradation, the approach used for the Kelly AFB demonstration.

The in situ process implies that treatment occurs in the ground itself. This characteristic distinguishes in situ biodegradation from the more conventional "pump-and-treat" technologies, in which contaminated groundwater is pumped to the surface and then treated. Of all other conventional remedial action technologies, pump-and-treat technologies most nearly match in situ biodegradation in overall treatment objectives and implementation steps as both involve pumping and reinjection of groundwater.

In situ biodegradation offers some distinct advantages over the pump-and-treat technologies. Because the active treatment zone is in the subsurface, in situ biodegradation has the potential to degrade contaminants adsorbed into the soil matrix. Desorption of contaminants from the soil may occur using pump-and-treat technologies. However, a larger volume of groundwater may require treatment in order to obtain the same level of contaminant removal from the soil as that achieved with in situ biodegradation. Theoretically, in situ biodegradation treatment would be accomplished faster since not as much water would have to be treated. Biodegradation actually destroys contaminants. Many pump-and-treat technologies such as carbon adsorption and air stripping merely change the location of contamination. Limitations of in situ biodegradation are somewhat site-related, as discussed previously in this report. Pump-and-treat technologies are not as site-dependent.

In situ biological degradation can be shown to be technically feasible for a number of waste sites based on progress of the demonstration at Kelly AFB. The cost-effectiveness of the technique is being demonstrated at the Biocraft site in Waldwick, New Jersey, and as more sites are remediated using this technique, costs should decrease. In situ biological degradation is another remedial action technology that should be considered for use at a number of waste sites along with removal and redisposal, containment, and other types of waste treatment technologies.

B. APPLICABILITY AND COST-EFFECTIVENESS OF IN SITU BIOLOGICAL DEGRADATION AT OTHER SITES

Applicability of in situ biological degradation at a given waste site can be determined by considering the following:

- Biological degradability of wastes present at the site, using indigenous microbes, as determined by laboratory testing.

- Presence of groundwater in the contamination zone to ensure that circulating groundwater can be used to deliver oxygen and nutrients.

- Permeability of subsurface materials to determine if groundwater can move at an adequate rate for treatment to be effective in a reasonable time period.

- Heterogeneity of subsurface materials to determine the effect of uneven groundwater flow or channelization of flow.

- Temperature variations and climate where *in situ* treatment will be used.

- Potential pathways to surface water bodies and drinking water wells.

- Regulatory requirements, such as permits for well drilling.

Applicability of *in situ* biological degradation is expected to be broad based on the above criteria.

Cost-effectiveness of *in situ* biological degradation is best determined by illustrative case histories. However, other than the field demonstration at Kelly, AFB, the only case history for which costs have been documented is the Biocraft site. As discussed in Section V, the total costs for remediation for this site will be roughly $1 to 1.5 million, based on a total capital cost of $925,678 and an annual operating cost of about $100,000. Projected costs for full-scale *in situ* biological degradation at the Kelly AFB site are approximately $1.7 million, based on 1 year of operation. The two sites are of approximately the same area (1.7 acres).

For the Biocraft site, the cost for the other major alternative considered (removal and redisposal), would have been approximately four times as high as the cost of the *in situ* treatment being conducted. For the Kelly AFB site, the costs for full-scale application were compared to pump-and-treat using aboveground granular activated carbon, removal and disposal, and containment alternatives, based on available information. Although the cost of the in situ treatment alternative appears high, compared to the pump-and-treat alternative and containment, continued demonstration at Kelly AFB, and collection of site-specific cost information for the other alternatives, will more closely define cost and effectiveness and will provide a more accurate comparison.

C. KEY FEATURES OF THE PROJECT AND POTENTIAL FOR FULL-SCALE APPLICATION AT KELLY AFB

Based on progress to date, continued uninterrupted operation of the demonstration at Kelly AFB for a 6 month to 1 year time period may result in at least partial degradation of organics shown to be degraded in laboratory treatability studies. These compounds include petroleum hydrocarbons, chlorinated aliphatics such as 1,1-DCE and 1,1-DCA, and chlorinated aromatics such as chlorobenzene. Key features of this demonstration are:

- This is one of the first, if not the first application of stabilized hydrogen peroxide as an oxygen source to degrade mixed hazardous wastes.
- The Kelly AFB site is a very difficult site for application of this technique because of heterogeneity and low permeability of subsurface materials. Therefore, a successful demonstration will indicate that technical feasibility may be established for a wider variety of sites than now believed.

Because of the heterogeneity and low permeability of subsurface materials, an elaborate system of closely spaced wells was needed to pump groundwater, add treatment solution, and inject the groundwater and treatment solution by gravity to the perched aquifer. Therefore, the projected cost for full scale application at the 1.7 acre site at Kelly AFB is very high at $1.7 million. For other sites where closely spaced well systems are not necessary, the costs for in situ biological degradation should be in the same range as for other, more conventional technologies.

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SECTION VII

RECOMMENDATIONS

This report documents activities associated with the first 17 months of this effort. This project is still in progress and treatment will continue for at least 6 months. This section contains short and long term recommendations for in situ biodegradation research.

Short-term recommendations for the field demonstration at Kelly AFB are:

- Continued operation of the system is likely to yield useful data concerning the degradation of site contaminants, and the limits of degradation achievable with this technique.
- System operation should be reevaluated and modifications of the system should be considered to improve upon the current injection capacity. These modifications include:
  - Identification of the mechanism by which the injection wells are being clogged and implementation of corrective action.
  - Redevelopment of the injection wells to increase injectivity.
  - Conversion of one or more pumping wells to injection wells.
  - Drilling additional injection wells.
  - Operation of the pumping wells at their maximum rate should be considered in order to promote increased circulation. This action would result in excess groundwater which would require storage, treatment, or discharge.

Recommendations for system monitoring for the field demonstration at Kelly AFB are:

- Increased monitoring should be performed on wells outside the demonstration system to provide early warning in the event of migration of materials from the treatment zone.

- One or two additional monitoring wells should be installed inside the demonstration area in order to evaluate groundwater chemical and biological conditions, because they would be unaffected by increased water temperatures caused by pumping wells.

Longer term recommendations for further investigation and application of in situ treatment technologies are:

- Based on the anaerobic degradation data generated by the laboratory treatability study for this project, it appears that further study leading to an eventual field demonstration may be warranted.
- For aerobic in situ biodegradation, an additional field demonstration and/or a full scale application at a site other than Kelly AFB may be warranted to obtain effectiveness and cost data for contrasting site characteristics including the number and type of contaminants present and permeability and homogeneity of subsurface materials.

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APPENDIX A

DRILLING LOGS

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JRB ASSOCIATES
A Company of Science Applications, Inc.
8400 Westpark Drive, McLean, Virginia 22102

DRILLING LOG

Project: In Situ
Owner: USAF
Well No.: BH-1

SEE FIGURE 4-1

Site Sketch

Location: Kelly AFB
80' SW of Paved
Storage Yard (E-1)

Reference Point: Land Surface

Reference Point Elevation: 637.5'ASL

Field Book No.: PP
Log By: P.A. Spooner
Driller: Shilstone
Rig Type: CME-75 Auger
Total Depth: 24.0'

	Date	Time
Drilling Started:	6/19/84	1312
Drilling Completed:	6/19/84	1710
Water Level:	21.2 BLS	

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
0'				
			8	R= 0.4' of Dark Brown Gravelly Silt Loam, Dry
		SS	7	
1'		1-1		
			5	
			8	
2'		SS		Recovered 0.8' Top 0.3' Dark Brown
			2	Gravelly Silt Loam Dry - w/Cobble
		1-2		0.5' of Dark Brown Silty Clay Loam - Dry
			8	
3'				
			11	Recovered 1.5' Top 0.4' Dark Brown
		SS		Silty Clay Loam Dry. 1.1' of Light
			18	Brown and Light Yellowish-Brown
4'		1-3		Sandy Clay, Somewhat moist, many Chert cobbles
			20	
			5	Recovered 1.4', 0.6' of yellowish-brown
5'				sandy clay, 0.4' of yellowish-brown gravelly

Page 1 of 4

DRILLING LOG

BH-1

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
5'		SS 1-4	4	clay, and 0.4' of dark brown fine sandy clay. All somewhat moist.
			8	
6'		M 1-1	4	Recovered 1.0'. Dark brown gravelly clay somewhat moist to moist.
		SS 1-5	7	
7'			9	
		C 1-1	11	Recovered 1.0'. Dark brown gravelly silty clay loam, moist, grades to yellowish-brown silty clay,
8'		SS 1-6	7	
			9	
9'		C	2	Recovered 1.3'. Pale yellow-brown silty clay, moist.
		SS 1-7	3	
10'			4	
		M 1-2	2	Recovered 0.95', 0.75' pale yellowish-brown silty clay, moist. 0.20' brown silty clay, moist
11'		SS 1-8		
			3	
12'		C 1-2	2	Recovered 0.5' of yellowish-brown silty clay, moist.
		SS 1-9		
13'				

DRILLING LOG

BH-1

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
13'			7	
			4	Recovered 0.75' dark brown silty clay, moist.
14'		SS 1-10	5	
			6	
15'			7	No recovery
		SS 1-11	9	
16'			12	
			6	Recovered 1.4' greyish-green clay with trace to few gravel grading to sandy clay - strong fuel-oil odor
17'		SS 1-12	14	
			10	
18'		C 1-3	10	Recovered 1.2' greyish-green fine sandy clay, moist - fuel-oil odor
		SS 1-13	15	
19'			16	
		M 1-3		Recovered 0.95' greyish-green sand, trace clay and silt, moist to wet, strong fuel-oil odor, common mottles.
20'		SS 1-14	50/5	
21'				

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (#)	DESCRIPTION
21'			19	Recovered 1.6' greyish-green sandy gravel, some silt, with small clay layer upper part, moist strong fuel-oil odor.
		SS 1-15	40	
22'			44	
		M 1-4	17	Recovered 1.8'. 1.4' greyish-green sandy gravel, moist. 0.4' of multi-colored silt loam, dry to somewhat moist.
23'		SS 1-6	14	
			16	
24'				
25'				
26'				
27'				
28'				
29'				

Page 4 of 4

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DRILLING LOG

Project: In Situ
Owner: USAF
Well No.: BH-2

SEE FIGURE 4-1

Site Sketch

Location: NW Corner of Storage Yard Kelly AFB
Reference Point: Land Surface
Reference Point Elevation: 641.3'ASL

Field Book No.: pp
Log By: P.A. Spooner
Driller: Shilstone
Rig Type: CME-75 Auger
Total Depth: 29.5'

	Date	Time
Drilling Started:	6/20/84,	0834
Drilling Completed:	6/20/84	1200
Water Level:	Dry	

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
0'				
			8	Recovered 1.35'. Dark brown silt loam
		SS	7	trace gravel, dry, common roots
1'		2-1	7	
			7	
2'		SS		Recovered 0.9'. Fill dark brown and light brown
			9	silt loam, few cobbles, very dry.
		2-2		
			8	
3'			8	Recovered 1.1', 0.5'. Dark brown silt
		SS		loam, common roots. 0.6' light brown
			9	and white fine sandy loam with some
4'		2-3		caliche gravel, dry, hard.
			10	
			8	
5'				Recovered 1.1'. Pale brown and white

Page 1 of 5

DRILLING LOG

BH-

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
5'		SS 2-4	9	fine sandy loam, less dense than above, much caliche.
			10	
6'			8	
		SS 2-5	9	Recovered 0.95'. 0.85' of pale brown and white fine sandy loam, much caliche. 0.1' of pale brown and white clay loam, somewhat moist.
7'			8	
			9	
8'		SS 2-6	10	Recovered 1.3'. Brown to pale brown clay loam, somewhat moist, common caliche gravel.
			10	
9'			6	Recovered 1.15'. Light yellowish-brown sandy clay loam, very homogenous
		SS 2-7	8	
10'			7	
			7	Recovered 1.15'. 0.95' of light yellowish-brown sandy clay loam. 0.2' of light yellowish-brown silty clay loam, moist, firm.
11'		SS 2-8	9	
			14	
12'		M 2-1	7	Recovered 1.0'. Light yellowish-brown silty clay loam, moist, firm.
		SS 2-9	9	
13'				

DRILLING LOG

BH-2

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
13'		G 2-1	11	
14'				
15'				Interval lost due to use of Rice University core barrel sampler. Sample could not be extruded in field.
16'		SS 2-9	8 9 15	Recovered 1.2'. Brown to yellowish-brown clay loam, moist, firm. Faint chemical odor.
17'				
18'		SS 2-10	6 7 12	Recovered 1.1'. Yellowish-brown sandy clay loam. Few pale mottles. No odor.
19'		M 2-2 SS 2-11	8 28	Recovered 1.2.'. 0.5'.of yellowish-brown sandy clay loam, moist. Few pale mottles. 0.7' of yellowish-brown chert gravel, dry.
20'		C 2-2	50/5 35	Recovered 0.9'. Yellowish-brown chert
21'				

Page 3 of 5

DRILLING LOG

BH-[illegible]

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
21'		SS 2-12	50/5	gravel in silty clay matrix, somewhat moist.
22'				
		SS 2-13	50/5	Recovered 0.65'. Yellowish-brown cherty gravel in silty clay matrix. Somewhat moist.
23'				
24'		SS 2-14	12 16 21	Recovered 1.6'. 0.3' of yellowish-brown cherty gravel in silty clay matrix. 1.3' of green and multi-colored silt loam, somewhat moist to dry, firm, slight solvent odor.
25'				
		SS 2-15	11 19 22	Recovered 1.65'. Green and multi-colored silt loam, somewhat moist, firm, slight solvent/pesticide odor.
26'				
27'		SS 2-16	13 22 28	Recovered 1.9'. Green and multi-colored silt loam, somewhat moist, firm, slight chemical odor.
28'		M 2-3	14 22	Recovered 1.3'. Green and multi-colored silt loam, somewhat moist, firm, slight chemical odor.
29'				

Page 4 of 5

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DRILLING LOG

BH-2

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
29'		C 2-3	25	
30'				
31'				
32'				
33'				
34'				
35'				
36'				
37'				

Page 5 of 5

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DRILLING LOG

Project: In Situ
Owner: USAF
Well No.: BH-3

SEE FIGURE 4-1

Site Sketch

Location: Kelly AFB
SE Side of Paved
Storage Area

Reference Point: Land Surface

Reference Point Elevation: 639.3

Field Book No.: ____ pp ____
Log By: P.A. Spooner
Driller: Shilstone
Rig Type: CME-75 Auger
Total Depth: 22.5'

	Date	Time
Drilling Started:	6/20/84	1622
Drilling Completed:	6/20/84	1635
Water Level:	Dry	

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
0'			7	
		SS 3-1	9	Recovered 0.85'. Dark brown and grey loamy fill, much caliche and other gravel, very dry.
1'			16	
			16	
2'		SS 3-2	21	Recovered 0.9'. Grey and brown loamy fill with much caliche, dry.
			15	
3'			6	
		SS 3-3	8	Recovered 0.8'. Pale yellowish-brown silty clay, some gravel, moist, very firm.
4'			8	
			6	
5'				

Page 1 **of** 4

DRILLING LOG

BH-3

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
5'		SS 3-4	6	Recovered 0.9'. Strong brown clay, some silt, trace gravel, moist, firm.
			8	
6'			5	
		SS 3-5	7	Recovered 1.0'. Pale greyish-brown silty clay, moist, very firm.
7'			10	
			6	
8'		SS 3-6	8	Recovered 1.4'. Pale greyish-brown silty clay, moist firm.
			11	
9'		M 3-1	6	Recovered 1.5'. Pale greyish-brown silty clay to clay, moist to very moist, firm.
		SS 3-7	8	
10'		C 3-1	13	
			5	Recovered 1.3'. Pale grey silty clay, moist, firm.
11'		SS 3-8	9	
			12	
12'			7	
		SS 3-10	30	Recovered 1.3'. 0.4' pale grey silty clay, moist, firm. 0.9' pale grey and yellowish-brown fine sandy clay, some
13'				

DRILLING LOG

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
13'			13	gravel, moist, firm.
			12	
14'		SS 3-10	30	Recovered 1.1'. 0.2' pale grey and yellowish-brown fine sandy clay, moist, firm. 0.9' pale grey clay, much gravel (sandstone and chert), some sand.
			36	
15'			26	
		SS 3-11	40/5	Recovered 0.9'. Grey and yellowish-brown gravel (chert) in clay matrix.
16'			40/5	
		M 3-2	26	Recovered 1.2'. Grey and yellowish-brown gravel (chert) in matrix.
17'		SS 3-12	30	
		C 3-2	50/5	
18'			7	Recovered 1.2'. Pale grey gravelly clay, moist, firm.
		SS 3-13	8	
19'			19	
		M 3-3	17	Recovered 0.8'. Dark grey gravelly clay, moist firm.
20'		SS 3-14	19	
			17	
21'				

DRILLING LOG

BH-3

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
21'		C 3-3	7	Recovered 1.9'. 0.6' grey clay gravel wet. 1.3' green and multi-colored silt loam moist.
		SS 3-15	9	
22'			14	
23'				
24'				
25'				
26'				
27'				
28'				
29'				

Page 4 of 4

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DRILLING LOG

Project: In Situu

Owner: USAF

Well No.: BH-4

SEE FIGURE 4-1

Site Sketch

Location: Kelly AFB West Central Portion of Paved Storage Area

Reference Point: Land Surface

Reference Point Elevation: 640.4'ASL

Field Book No.: PP

Log By: P.A. Spooner

Driller: Shilstone

Rig Type: CME-75 Auger

Total Depth: 24'

	Date	Time
Drilling Started:	6/21/84	0924
Drilling Completed:	6/21/84	1158
Water Level:	Dry	

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
0'				0' - 0.5' no sample - cut through 0.15' asphalt
		SS 4-1	5	Recovered 0.7'. 0.2' light grey gravel. 0.5' very dark brown sludge. Strong chemical odor.
1'			8	
			7	Recovered 0.6'. Very dark brown and yellowish-brown sludge, some gravel, chemical odor
2'		SS 4-2	10	
			11	
3'			5	Recovered 0.75'. Dark brown sludge, chemical/fuel odor.
			4	
4'		SS 4-3	4	
		M 4-1	6	
5'				

Page 1 of 4

DRILLING LOG

BH-4

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
5'		SS 4-4	6	Recovered 1.3'. Pale grey and grey, fine-grained sludge, moist, firm, strong chemical odor
		C 4-1	6	
6'			6	Recovered 1.1'. ~0.25 dark greyish-brown sludge, 0.95' light greyish-brown silty clay loam, some gravel (caliche) moist, firm, strong chemical odor.
		SS 4-5	6	
7'			8	
			7	Recovered 1.1'. Pale yellowish-brown silty clay loam, moist, firm, mild odor.
8'		SS 4-6	7	
			9	
9'			5	Recovered 1.5'. Yellowish-brown silty clay loam, common caliche gravel, moist, firm, mild odor.
		SS 4-7	7	
10'			10	
			6	Recovered 1.4'. Yellowish-brown silty clay loam, common caliche gravel moist, firm, mild odor.
11'		SS 4-8	8	
			11	
12'			6	Recovered 1.4'. Yellowish-brown silty clay loam to silty clay, some caliche gravel.
		SS 4-9	8	
13'				

Page 2 of 4

DRILLING LOG

BH-

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
13'			11	
		SS 4-10	6	Recovered 1.0'. Pale grey and yelowish-brown silty clay, moist firm.
14'			10	
			14	
15'		M 4-2	8	Recovered 1.4'. Pale grey and yellowish-brown silty clay, moist, firm
		SS 4-11	11	
16'		C 4-2	15	
		SS 4-12	8	Recovered 1.4'. 1.2' of pale grey and pale yellowish-brown silty clay, moist firm, 0.2' of multi-colored sandy clay.
17'			10	
			16	
18'		SS 4-13	8	Recovered 1.35'. Yellowish-brown and multi-colored sandy-clay with some gravel. Gravel is stained black in places
			10	
19'			15	
		SS 4-14	8	Recovered 1.5'. Pale grey clay, moist firm, few fine gravel toward bottom.
20'			9	
			15	
21'				

Page 3 of 4

DRILLING LOG

BH-4

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
21'			6	Recovered 1.3'. Pale grey clay, moist, firm, few fine gravel, mild organic chemical odor.
		SS 4-15	9	
22'			13	
		M 4-3	8	
23'		SS 4-16	29	Recovered 1.55'. 1.05' Pale grey clay, moist, firm, mild chemical odor. 0.5' Yellowish-brown clayey gravel.
		C 4-3	50/4	
24'				
25'				
26'				
27'				
28'				
29'				

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DRILLING LOG

Project: In Situu
Owner: USAF
Well No.: BH-5

SEE FIGURE 4-1

Site Sketch

Location: Kelly AFB
Area E-1, East -
Central Paved
Storage Yard

Reference Point: Land Suface

Reference Point Elevation: 641.0'ASL

Field Book No.: ____pp____
Log By: P.A Spooner
Driller: Shilstone
Rig Type: CME-75 Auger
Total Depth: 24'

	Date	Time
Drilling Started:	6/21/84	1430
Drilling Completed:	6/22/84	0940
Water Level:	Dry	

Depth (feet)	Graphic Log	Sample Type and Number	Blow Count (N)	DESCRIPTION
0'				
				0.0'-0.5' -No sample - 0.2' Asphalt
		SS	4	Black top, 0.3' gravel
1'		5-1		Recovered 0.4'. Dark brown, fine-
			3	grained sludge, strong chemical odor.
			2	
2'				Recovered 0.7'. Dark brown, fine-
		SS	3	grained sludge, moist, strong
		5-2		chemical odor.
			9	
3'				
			7	Recovered 0.85'. Dark brown sludge
		SS		with some sand and gravel; strong
		5-3	7	chemical and sulfur odor.
4'				
			7	
			4	
5'				Recovered 0.6'. Dark brown fine

Page 1 of 4

DRILLING LOG

BH-5

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
5'		SS 5-4	5 10	sludge with some gravel, moist, strong odor.
6' 7'		SS 5-5	6 6 4	Recovered 0.7'. Dark brown fine sludge with some gravel, moist, strong odor.
8'		M 5-1 SS 5-6 C 5-1	5 3 3	Recovered 0.7'. Dark brown fine sludge with some gravel, moist, strong odor.
9' 10'		SS 5-7	3 5 6	Recovered 0.3'. Dark brown fine sludge with some gravel, moist, strong odor.
11'		SS 5-8	2 2 6	Recovered 1.0'. 0.25'. Dark brown fine sludge, moist, strong odor. 0.75' of pale yellowish-brown sandy clay with green(Cr) staining.
12' 13'		SS 5-9	6 8	Recovered 1.0'. Pale yellowish-brown sandy clay, moist, firm, mild odor.

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DRILLING LOG

BH-

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
13'				
			10	
			6	Recovered 1.1'. Pale yellowish-brown
14'		SS	10	sandy clay, moist, firm, mild odor.
		5-10		
			13	
15'		M		
		5-2	7	Recovered 1.5'. Pale yellowish-brown
		SS	12	sandy clay, moist, firm, mild odor.
		5-11		
16'		C	15	
		5-2		
			8	
17'		SS		Recovered 1.45'. Pale grey and light
		5-12	13	yellowish-brown clay, moist, very firm.
			13	
18'				
			5	Recovered 1.4'. Pale grey and yellowish-brown
		SS	9	sandy clay, moist, firm, much
19'		5-13		mottling and manganese concretions
			11	
			7	
20'		SS		Recovered 1.5'. Pale grey and yellowish-brown
			10	clay, moist, firm, much mottling,
		5-14		mild organic chemical odor.
			11	
21'				

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DRILLING LOG

BH-3

Depth (feet)	Graphic Log	Sample type and Number	Blow Count (N)	DESCRIPTION
21'		M 5-3 SS 5-15	8 9	Recovered 18.'. Pale grey and yellowish-brown clay, moist, firm, much mottling, mild odor, bottom 0.6' with reddish-brown sand partings.
22'		C 5-13	12 6	Recovered 1.5'. Pale gray clay with yellowish-brown and brown mottles, moist, firm, mild organic chemical odor.
23'		SS 5-16	9 12	
24'				
25'				
26'				
27'				
28'				
29'				

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APPENDIX B

FIELD HYDROLOGY STUDIES

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TABLE B-1. WELL SPECIFICATIONS

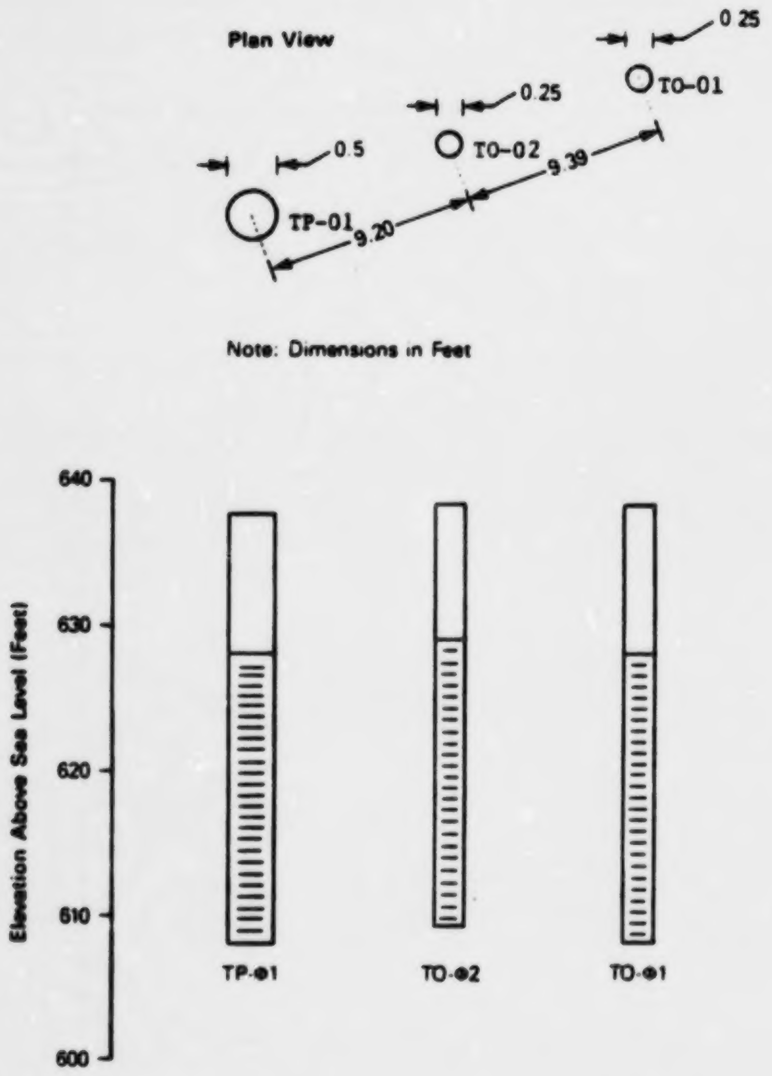
Well	Bore Diam. (inches)	PVC Casing Diam. (ft BLS[3])	Total Depth (ft BLS)	Top of Screen (ft BLS)	Casing Height Elevation (ft ALS[4])	Casing Height Elevation (ft ASL)
[1]TP-01	10	6	29.5	9.5	2.97	640.53
[2]TO-02	8	4	29.3	9.3	2.53	640.93
TO-01	8	4	30.2	10.2	2.62	640.86

1. Pumping Well (TP-01)
2. Observation Well (TO-02)
3. Below Land Surface (BLS)
4. Above Land Surface (ALS)

TABLE B-2. WATER LEVEL ELEVATIONS

	Elevation Land Surface (ft ASL[1])	Elevation Top of Casing (ft ASL)	Water Level (ft BTC[2])	Water Level (ft ASL)
Well AA	640.8	643.59	26.53	617.06
Well BB	639.6	642.58	28.37	614.21
Well CC	635.8	638.67	25.22	613.45
Test Pumping Well-01	637.5	640.53	23.59	616.94
Test Observation Well-02	638.4	640.93	23.47	617.46
Test Observation Well-01	638.2	640.86	23.44	617.42
Borehole 8	636.6[3]	-	15.35 BLS[4]	621.25
Borehole B used for Permeability Testing	638.0[3]	-	20.90 BLS[4]	617.10

1. Above sea level
2. Below top of casing
3. Interpolated from USGS Topographic Map
4. Below land surface


Plan View
0.25
0.25
0.5
TO-01
TO-02
TP-01
9.39
9.20
640
630
620
610
600
Elevation Above Sea Level (Feet)
TP-01
TO-02
TO-01

Note: Dimensions in Feet

Note: Horizontal Not to Scale

Figure B-1. Horizontal and Vertical Dimensions of Test Well Set Up

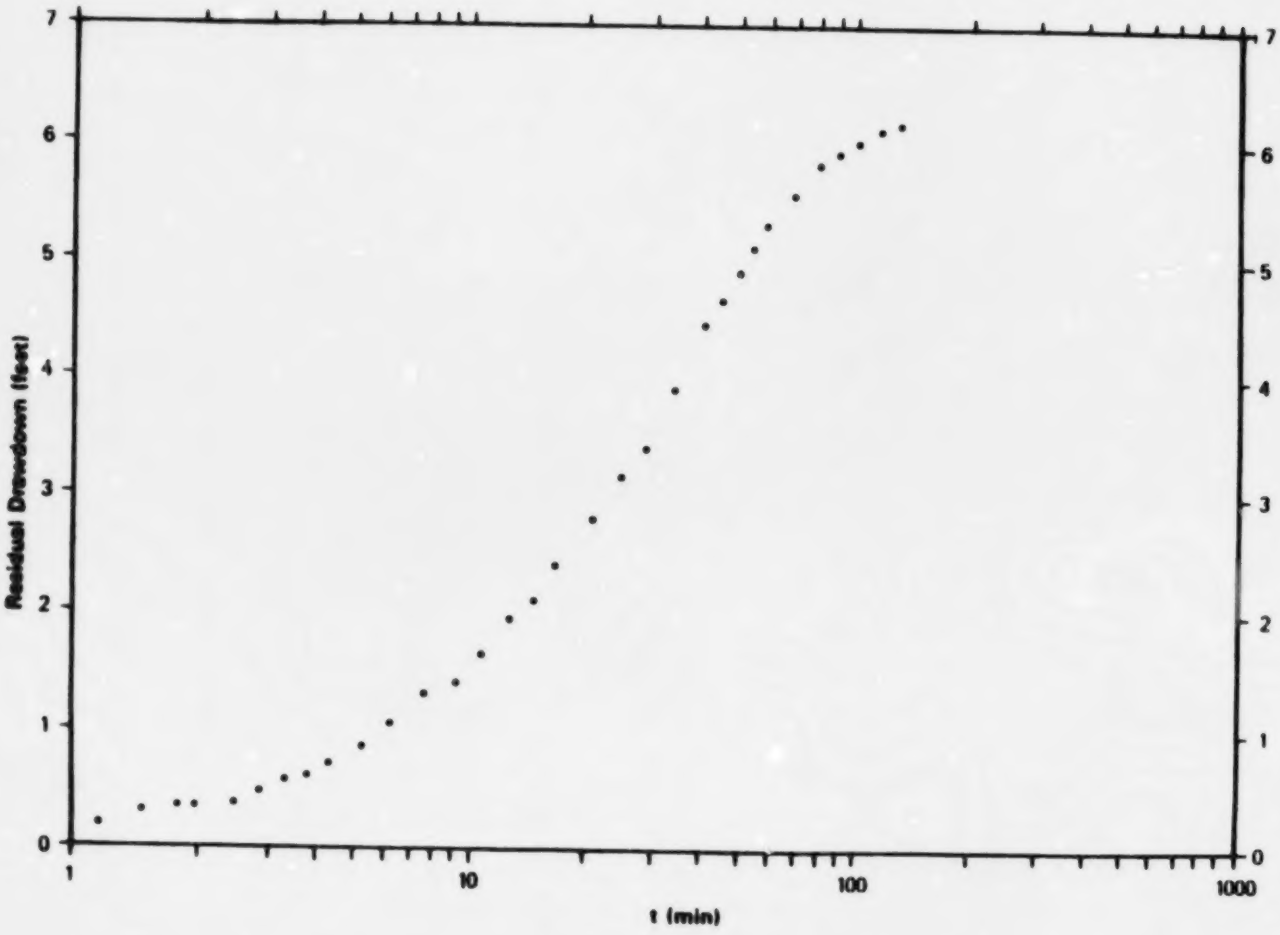


Figure B-2. Residual Drawdown vs. Time for Recovery Test 1/28/85 Q_o = 0.4 gpm

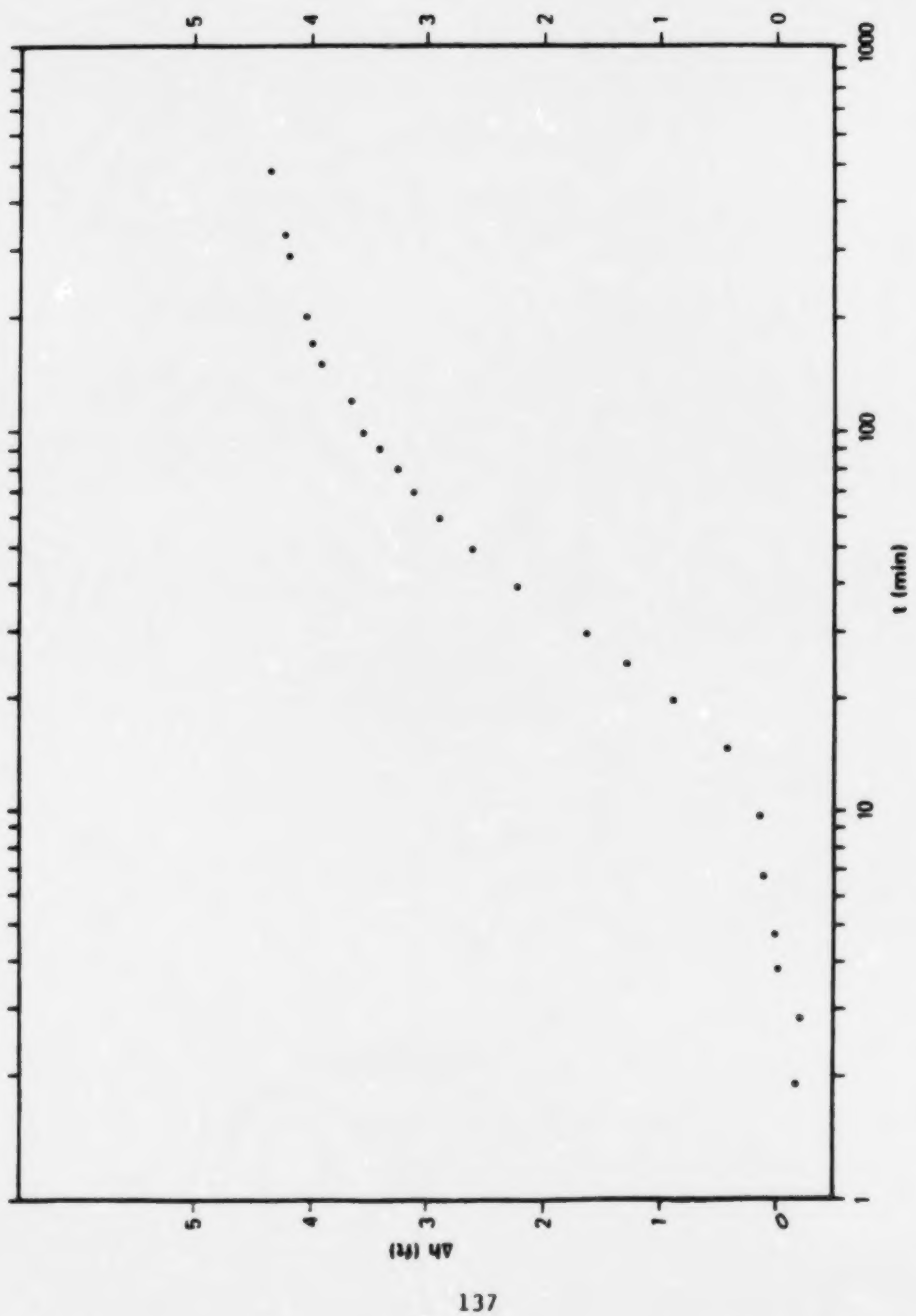


Figure B-3. Δh Versus Time for Injection Test 1/31/85 Q_I = 0.3 gpm

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APPENDIX C

CHEMICAL AND MICROBIAL CHARACTERIZATION OF SITE E-1

TABLE C-1. RESULTS OF INORGANIC ANALYSES(1)

ES Log No.	Sample Description2	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn	Cr^{+6}	CN^{-1}
06-1030	1-1 Soil BH-1	50.2	<0.5	1.4	7.7	143	23.7	77.3	<0.2	26.3	<0.2	4.0	<10	43.7	<0.05	0.5
06-1031	1-2 Soil BH-1	58.9	<0.5	1.2	3.6	63.9	13.7	39.1	<0.2	25.0	<0.2	8.0	<10	48.1	<0.05	<0.5
06-1032	1-3 Soil BH-1	61.7	<0.5	<1	4.9	15.6	11.5	37.5	<0.2	22.3	<0.2	5.5	<10	32.2	<0.05	<0.5
06-1033	2-1 Soil BH-2	68.1	<0.5	<1	4.7	37.5	10.5	37.3	<0.2	20.6	<0.2	5.7	<10	27.8	<0.05	<0.5
06-1034	2-2 Soil BH-2	60.8	<0.5	<1	4.3	27.4	13.2	36.3	0.2	20.3	<0.2	3.4	<10	31.7	<0.05	0.5
06-1035	2-3 Soil BH-2	34.8	<0.5	1.4	3.1	110	7.8	29.2	<0.2	20.0	<0.2	3.8	<10	74.7	<0.05	0.5
06-1036	3-1 Soil BH-3	40.1	<0.5	2.3	3.2	29.2	13.4	39.5	<0.2	21.2	<0.2	4.3	<10	46.1	<0.05	<0.5
06-1037	3-2 Soil BH-3	48.5	<0.5	<1	4.8	144	16.9	47.5	0.3	25.7	<0.2	4.9	<10	47.8	0.21	<0.5
06-1038	3-3 Soil BH-3	68.8	<0.5	2.0	4.1	303	10.3	33.0	0.3	23.0	<0.2	4.5	<10	53.9	0.07	<0.5
06-1039	4-1 Soil BH-4	57.4	<0.5	1.4	5.5	24.4	13.0	46.5	<0.2	25.5	<0.2	4.3	<10	65.7	<0.05	<0.5
06-1040	4-2 Soil BH-4	68.8	<0.5	<1	4.6	30.6	14.2	41.4	0.2	24.2	<0.2	4.2	<10	37.0	0.16	<0.5
06-1041	4-3 Soil BH-4	57.1	<0.5	<1	5.2	147	8.4	38.9	0.2	21.8	<0.2	5.2	<10	24.0	<0.05	<0.5
06-1042	5-1 Soil BH-5	51.5	<0.5	1.1	5.2	59.8	16.6	70.4	<0.2	23.8	<0.2	5.5	<10	54.2	<0.05	<0.5
06-1043	5-2 Soil BH-5	43.4	<0.5	1.3	4.4	65.2	14.6	35.2	<0.2	20.9	<0.2	3.6	<10	34.2	1.4	<0.5
06-1073	5-3 Soil BH-5	48.8	<0.5	1.5	4.5	85.4	10.0	40.8	<0.2	22.9	<0.2	3.9	<10	40.5	2.1	<0.5
06-1076	Well AA	<0.05	<0.005	<0.05	0.02	0.04	0.04	0.11	<0.002	0.06	<0.002	<0.01	<0.1	0.31	<0.05	<0.001
06-1077	Well BB	<0.05	<0.005	<0.05	<0.01	0.06	0.06	0.12	<0.002	0.06	<0.002	<0.01	<0.1	0.12	<0.05	-
06-1078	Well CC	<0.05	<0.005	<0.05	<0.01	0.02	0.02	0.17	<0.002	<0.05	<0.002	0.07	<0.1	0.09	<0.05	-

1 All results are expressed in units of µg/g for soils and µg/ml for water.

2 Sampled 19-22 June 1984.

TABLE C-2. RESULTS OF ORGANIC ANALYSES:(1) PURGEABLES (PRIORITY POLLUTANTS METHOD 601)

ES Log No.	Sample Description 2	Carbon tetrachloride	Chloroform	1,1-Dichloro-ethane	1,1-Dichloro-ethylene	Tetrachloro-ethylene	trans-1,2-Dichloro-ethylene	1,1,1-Trichloro-ethane	Trichloro-ethylene	Vinyl chloride
06-1030	1-1 Soil BH-1	-	-	-	-	-	-	-	-	-
06-1031	1-2 Soil BH-1	-	-	-	-	-	-	-	-	-
06-1032	1-3 Soil BH-1	-	-	-	-	-	-	-	-	-
06-1033	2-1 Soil BH-2	-	-	-	-	-	-	-	-	-
06-1034	2-2 Soil BH-2	-	-	-	-	-	-	-	-	-
06-1035	2-3 Soil BH-2	-	-	-	-	-	-	-	-	-
06-1036	3-1 Soil BH-3	-	-	-	-	-	-	-	-	-
06-1037	3-2 Soil BH-3	-	-	-	-	-	-	-	-	-
06-1038	3-3 Soil BH-3	-	-	-	-	-	-	-	-	-
06-1039	4-1 Soil BH-4	-	-	-	-	-	-	-	-	-
06-1040	4-2 Soil BH-4	-	-	-	-	-	-	-	-	-
06-1041	4-3 Soil BH-4	-	-	-	-	-	-	-	-	-
06-1042	5-1 Soil BH-5	-	-	-	-	-	-	-	-	-
06-1043	5-2 Soil BH-5	-	-	-	-	-	-	-	-	-
06-1073	5-3 Soil BH-5	-	-	-	-	-	-	-	-	-
06-1076	Well AA	-	-	67.	-	-	7700.	76.	-	770.
06-1077	Well BB	117.	110.	124.	121.	125.	120.	121.	116.	-
06-1078	Well CC	-	-	-	-	15000.	2200.	-	6700.	-
06-1035	Spike A	-	-	-	-	-	-	-	-	-
06-1035	Spike B	-	-	-	-	-	-	-	-	-
06-1038	Spike A	-	-	-	-	-	-	-	-	-
06-1038	Spike B	-	-	-	-	-	-	-	-	-
06-1077	Spike A	-	640.	-	-	-	29000.	-	5400.	-
06-1077	Spike B	-	590.	-	-	-	26000.	-	4300.	-
06-1076	Field Blank	-	1.2	-	-	-	-	-	-	-
06-1075	Trip Blank	-	1.1	-	-	-	-	-	-	-
Soil Blank	Soil Blank	-	-	-	-	-	-	-	-	-

1 All results are expressed in units of parts per billion (ppb).

2 Sampled 19-22 June 1984.

TABLE C-3. RESULTS OF ORGANIC ANALYSES:(1) VOLATILE FRACTION (PRIORITY POLLUTANTS METHOD 624)

ES Log No.	Sample Description 2	Benzene	Chloro-benzene	1,1-Dichloro-ethane	1,1-Dichloro-ethylene	Ethyl-benzene	Methylene chloride	Tetra-chloro-ethylene	Toluene	trans-1,3-Dichloropropene	1,1,1-Trichloro-ethane	Trichloro ethylene
06-1030	1-1 Soil BH-1	0.002	-	-	-	-	-	0.001	0.004	0.006	0.006	0.001
06-1031	1-2 Soil BH-1	-	-	-	-	-	0.06	-	0.01	-	0.10	0.01
06-1032	1-3 Soil BH-1	-	0.093	-	-	0.006	-	-	0.038	-	-	-
06-1033	2-1 Soil BH-2	-	-	-	-	-	0.04	-	0.005	-	-	-
06-1034	2-2 Soil BH-2	-	-	-	-	-	-	-	-	-	0.97	-
06-1035	2-3 Soil BH-2	-	-	-	-	-	-	-	-	0.013	-	0.016
06-1036	3-1 Soil BH-3	-	-	-	-	-	-	-	-	-	-	-
06-1037	3-2 Soil BH-3	-	-	0.013	-	-	0.072	0.022	-	-	-	-
06-1038	3-3 Soil BH-3	-	-	-	-	-	-	-	-	-	-	-
06-1039	4-1 Soil BH-4	-	-	-	-	-	-	-	0.009	0.14	-	-
06-1040	4-2 Soil BH-4	-	-	-	-	-	-	-	-	0.18	-	-
06-1041	4-3 Soil BH-4	-	-	-	-	-	-	-	0.022	-	-	0.90
06-1042	5-1 Soil BH-5	-	-	-	-	0.049	0.18	0.019	0.13	-	-	0.024
06-1043	5-2 Soil BH-5	-	0.012	-	-	-	-	-	-	1.7	-	0.082
06-1073	5-3 Soil BH-5	-	-	-	-	-	-	0.007	-	-	-	-
06-1076	Well AA	-	-	-	-	-	-	-	-	-	-	-
06-1077	Well BB	-	-	-	-	91.	-	-	-	-	-	-
06-1078	Well CC	-	-	-	-	-	-	-	-	-	-	-
06-1035	Spike A	0.23	0.18	-	0.61	-	-	-	0.21	-	-	0.19
06-1035	Spike B	0.21	0.17	-	0.73	-	-	0.005	0.19	-	-	0.20
06-1038	Spike A	0.30	0.17	-	0.62	-	-	-	0.18	-	-	0.20
06-1038	Spike B	0.20	0.15	-	0.59	-	-	-	0.17	-	-	0.18
06-1077	Spike A	-	-	-	-	-	-	-	-	-	-	-
06-1077	Spike B	-	-	-	-	-	-	-	-	-	-	-
06-1074	Field Blank	-	-	-	-	-	-	-	-	-	-	-
06-1075	Trip Blank	-	-	-	-	-	-	-	-	-	-	-
Soil Blank	Soil Blank	-	-	-	-	-	-	-	-	-	-	-

1 All results are expressed in units of parts per million (ppm).

2 Sampled 19-22 June 1984.

TABLE C-4. RESULTS OF ORGANIC ANALYSES:(1) BASE/NEUTRAL FRACTION (PRIORITY POLLUTANTS METHOD 625)

ES Log No.	Sample Description 2	Anthracene	bis(2-Ethylhexyl) phthalate	1,2-Dichloro-benzene	1,3-Dichloro-benzene	1,4-Dichloro-benzene	Di-n-butyl-phthalate	Dioctyl-phthalate	Naphthalene	1,1,2,2-Tetra chloroethylene	1,2,4-Trichloro-benzene
06-1030	1-1 Soil BH-1	-	-	-	-	-	-	-	-	-	-
06-1031	1-2 Soil BH-1	-	60.	-	-	-	-	-	-	-	-
06-1032	1-3 Soil BH-1	-	30.	-	-	-	16.	-	-	-	-
06-1033	2-1 Soil BH-2	-	60.	-	-	-	-	-	-	-	-
06-1034	2-2 Soil BH-2	-	78.	-	-	-	-	-	-	-	-
06-1035	2-3 Soil BH-2	-	22.	0.15	-	-	-	-	-	-	-
06-1036	3-1 Soil BH-3	-	60.	-	-	-	-	18	-	-	-
06-1037	3-2 Soil BH-3	-	62.	-	-	-	-	-	-	-	-
06-1038	3-3 Soil BH-3	-	-	-	-	-	16.	-	-	-	-
06-1039	4-1 Soil BH-4	-	-	0.16	-	-	14.	-	-	-	-
06-1040	4-2 Soil BH-4	-	20.	-	-	-	-	-	-	-	-
06-1041	4-3 Soil BH-4	-	26.	-	-	-	-	-	-	-	-
06-1042	5-1 Soil BH-5	<1.0	12.	22.	3.2	13.	-	-	5.2	-	<1.0
06-1043	5-2 Soil BH-5	-	20.	-	-	-	-	-	-	-	-
06-1073	5-3 Soil BH-5	-	30.	-	-	0.35	-	-	-	0.007	-
06-1076	Well AA	-	0.023	0.046	0.014	0.20	0.005	-	0.005	-	0.001
06-1077	Well BB	-	0.017	-	0.007	0.003	0.006	-	-	-	-
06-1078	Well CC	-	0.041	-	<0.001	<0.001	-	-	-	-	-
06-1035	Spike A	-	-	-	-	-	-	-	-	-	-
06-1035	Spike B	-	-	-	-	-	-	-	-	-	-
06-1038	Spike A	-	-	-	-	-	-	-	-	-	-
06-1038	Spike B	-	-	-	-	-	-	-	-	-	-
06-1077	Spike A	-	-	-	-	-	-	-	-	-	-
06-1077	Spike B	-	-	-	-	-	-	-	-	-	-
06-1074	Field Blank	-	0.44	-	-	-	-	-	-	-	-
06-1075	Trip Blank	-	0.36	-	-	<0.001	-	-	-	-	-
Soil Blank	Soil Blank	-	8.	-	-	-	-	-	-	-	-

1 All results are expressed in units of parts per million (ppm).

2 Sampled 19-22 June 1984.

TABLE C-5. COMPOUNDS PRESENT IN KELLY AFB GROUNDWATER WELL TP-01[a]

Compound	Concentration (ng/ml)
Phenol	1.6
1,2-Dichlorobenzene	0.8
1,3-Dichlorobenzene	3.2
1,4-Dichlorobenzene	3.0
Isophorone	0.8
Benzoic acid	1.5
Di-N-butyl phthalate	0.8
Bis(2-ethylhexyl)phthalate	2.4
Dioctylphthalate	0.2
Trichloroethene	110.0
Methylbenzene (Toluene)	1.3
Tetrachloroethene	410.0
3,3,3-Trichloro-1-propene	0.3
Chlorobenzene	11.0
2-Cyclohexen-1-ol	11.0
2-Chlorocyclohexene	1.0
2-Cyclohexen-1-one	13.0
trans-Decahydronaphthalene	0.3
2,3-Dihydro-4-methyl-1H-indene	3.0
2-Ethyl-1,3-dimethylbenzene	1.0
2,3-Dihydro-1,3-dimethyl-1H-indene	0.3
2,3-Dihydro-1,1-dimethyl-1H-indene	2.0
1-Ethyl-2,3-dimethylbenzene	0.7
Bromocyclohexane	4.0

[a] Sampled January 1985

TABLE C-6. MEAN NUMBER OF GREEN-FLUORESCING CELLS PER WET GRAM SUBSURFACE SAMPLE

Site	depth	cells/wet gram sample ± standard deviation
Borehole 1.	shallow	1.68×10^{8}
Borehole 1.	middle	1.02×10^{8}
Borehole 1.	deep	1.45×10^{8}
Borehole 2.	shallow	$4.3 \times 10^{7} \pm 2.4 \times 10^{7}$
Borehole 2.	middle	$2.7 \times 10^{7} \pm 1.41 \times 10^{7}$
Borehole 2.	deep	$3.6 \times 10^{7} \pm 2.6 \times 10^{7}$
Borehole 3.	shallow	$2.5 \times 10^{7} \pm 1.08 \times 10^{7}$
Borehole 3.	middle	$2.1 \times 10^{7} \pm 7.2 \times 10^{6}$
Borehole 3.	deep	$1.37 \times 10^{7} \pm 4.8 \times 10^{6}$
Borehole 4.	shallow	$1.91 \times 10^{7} \pm 1.1 \times 10^{7}$
Borehole 4.	middle	$1.68 \times 10^{7} \pm 4.8 \times 10^{6}$
Borehole 4.	deep	$2.7 \times 10^{7} \pm 7.4 \times 10^{6}$
Borehole 5.	shallow	$1.57 \times 10^{7} \pm 1.12 \times 10^{6}$
Borehole 5.	middle	$7.6 \times 10^{6} \pm 3.1 \times 10^{6}$
Borehole 5.	deep	$9.2 \times 10^{6} \pm 4.8 \times 10^{6}$

TABLE C-7. NUMBER OF COLONY FORMING UNITS PER WET GRAM SUB-SURFACE SAMPLE

Site	Media						
	L-PGYEA	L-PGYEA 1,4 Cl◆	H-PGYEA	H-PGYEA 1,4 Cl◆	AA-Agar	SB-Agar	CC-Agar
Bore-hole #1							
shallow	6.850[1] ± 0.036[2]	6.841 ± 0.074	>6.47	>6.47	6.681 ± 0.097	6.664 ± 0.106	6.631 ± 0.093
intermediate	5.503 ± 0.145	5.449 ± 0.194	5.337 ± 0.122	5.429 ± 0.168	5.492 ± 0.072	5.521 ± 0.053	5.470 ± 0.125
deep	2.831 ± 0.260	2.878 ± 0.174	2.985 ± 0.026	2.952 ± 0.281	3.136 ± 0.121	3.369 ± 0.120	2.979 ± 0.091
Bore-hole #2							
shallow	3.938 ± 0.140	3.876 ±.038	3.741 ± 0.186	3.618 ± 0.022	4.376 ± 0.073	4.253 ± 0.307	4.007 ± 0.093
intermediate	2.852 ± 0.641	2.497 ± 0.861	3.000 ± 0.139	3.183 ± 0.120	3.736 ± 0.119	3.522 ± 0.109	3.208 ± 0.085
deep	5.033 ± 0.046	5.060 ± 0.116	5.056 ± 0.124	5.018 ± 0.051	5.093 ± 0.30	4.971 ± 0.221	4.984 ± 0.030
Bore-hole #3							
shallow	4.915 ± 0.022	4.929 ± 0.031	4.272 ± 0.216	3.906 ± 0.293	4.948 ± 0.114	5.003 ± 0.020	4.906 ± 0.101
intermediate	6.319 ± 0.071	6.375 ± 0.075	6.486 ± 0.036	6.435 ± 0.048	6.563 ± 0.109	6.528 ± 0.128	6.343 ± 0.098
deep	6.449 ± 0.078	6.380 ± 0.124	6.154 ± 0.018	6.220 ± 0.055	6.544 ± 0.052	6.598 ± 0.059	6.713 ± 0.199
Bore-hole #4							
shallow	3.301 ± --	3.615 ± 0.282	3.418 ± 0.392	3.366 ± 0.102	3.301 ± 0.426	3.873 ± 0.174	3.300 ± 0.130
intermediate	4.716 ± --	5.047 ± 0.056	4.746 ± 0.028	4.767 ± 0.037	5.066 ± 0.019	5.106 ± 0.034	5.089 ± 0.227
deep	2.602 ± --	2.502 ± 0.174	2.418 ± 0.392	2.500 ± 0.439	2.239 ± 0.327	2.282 ± 0.488	<2.00
Bore-hole #5							
shallow	6.105 ± 0.036	6.153 ± 0.152	6.214 ± 0.150	6.121 ± 0.175	6.314 ± 0.198	6.171 ± 0.122	6.158 ± 0.056
intermediate	4.739 ± 0.135	4.806 ± 0.068	4.985 ± 0.008	4.733 ± 0.066	4.929 ± 0.112	5.308 ± 0.100	4.879 ± 0.133
deep	5.571 ± 0.080	5.604 ± 0.042	5.467 ± 0.130	5.577 ± 0.063	5.583 ± 0.079	5.577 ± 0.094	5.557 ± 0.098

[1], Mean Log. Number Cells

[2], Standard Deviation

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APPENDIX D

LABORATORY BIODEGRADATION STUDY

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TABLE D-1. MINERAL NUTRIENT MEDIA FOR AEROBIC MICROCOSMS[a]

Nutrient	Concentration
NH_4Cl	5.0 g/l
KH_2PO_4	3.4
Na_2HPO_4	6.6
$MgSO_4.7H_2O$	0.2
$CaCl_2.2H_2O$	0.01
$FeCl_3$	0.01
H_3BO_4	1.176 μg/l
$MnSO_4$	1.0
$ZnSO_4$	7.0
$CuSO_4$	5.0
$NaMoO_4$	1.0

adjust to pH 7

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[a] Reference 19

TABLE D-2. MINERAL NUTRIENT MEDIA FOR ANAEROBIC MICROCOSMS (After Shelton's Revised Anaerobic Mineral Media)[a]

Nutrient	Concentration, mg/l	
K_2HPO_4	350	Phosphate Buffer
KH_2PO_4	270	
NH_4Cl	530	Mineral Salts
$CaCl_2 \cdot 2H_2O$	75	
$MgCl \cdot 6H_2O$	100	
$FeCl_2 \cdot 4H_2O$	20	
$MnCl_2 \cdot 4H_2O$	0.5	Trace Metals
H_3Bo_3	0.05	
$ZnCl_2$	0.05	
$CuCl_2$	0.03	
$NaMo_4 \cdot 2H_2O$	0.01	
$CoCl_2 \cdot 6H_2O$	0.5	
$NiCl_2 \cdot 6H_2O$	0.05	
Na_2SeO_3	0.05	
$NaHCO_3$	1200	
$Na_2S \cdot 9H_2O$ (optional)	500	

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[a] Reference 20

TABLE D-3. REDOX, DISSOLVED OXYGEN, pH, AND VIABILITY DATA FOR HYDROGEN PEROXIDE-TREATED AEROBIC MICROCOSMS

Sample #	Redox mV	Volume of Sample Analyzed, ml	Temp °C	DO ppm	pH	H_2O_2 ppm	Bacterial Growth
1-H-2		14.2	22.0	3.2	7.58		+
1-H-6		15.2	21.5	3.2	7.33		+
1-H-10		16.0	21.5	3.1	7.44		+
24-H-1	163	15.8	21.5	5.2	7.34		+
24-H-14	173	15.4	20.0	4.8	7.38		+
24-H-15	160	16.0	22.0	4.2	7.39		+
49-H-4		14.4	19.0	4.8	7.32		+
49-H-7		13.6	19.0	5.8	7.25		+
49-H-12		13.8	20.0	6.2	7.22		+
100-H-5	154	13.2	21.0	4.0	7.38	17.3	+
100-H-9	157	13.6	21.0	3.6	7.30	12.8	+
100-H-11	162	15.2	21.0	3.2	7.30	17.3	+

TABLE D-4. REDOX, DISSOLVED OXYGEN, pH, AND VIABILITY DATA FOR GAMMA-IRRADIATED, HYDROGEN PEROXIDE-TREATED, AEROBIC STERILE CONTROL MICROCOSMS

Sample #	Redox mV	Volume of Sample Analyzed, ml	Temp °C	DO ppm	pH	H_2O_2 ppm	Bacterial Growth
1-HS-6		13.8	22.5	3.2	7.60		-
1-HS-9		13.6	23.0	3.2	7.54		-
1-HS-15		15.2	22.0	3.3	7.59		-
24-HS-2	165	13.8	22.0	6.4	7.36		-
24-HS-13	160	16.2	22.0	6.8	7.38		-
49-HS-1		15.0	19.5	9.0	7.27		-
49-HS-14		14.0	19.0	9.0	7.27		-
100-HS-11	167	14.2	22.0	6.6	7.40	10.9	-
100-HS-12	157	15.0	22.0	6.7	7.40	10.5	-

TABLE D-5. REDOX, DISSOLVED OXYGEN, pH, AND VIABILITY DATA FOR OXYGEN-TREATED AEROBIC MICROCOSMS

Sample #	Redox mV	Volume of Sample Analyzed, ml	Temp °C	DO ppm	pH	H_2O_2 ppm	Bacterial Growth
1-0-1		15.6	22.0	3.4	7.39		+
1-0-12		16.2	22.5	3.8	7.26		+
1-0-14		15.0	22.0	3.6	7.39		+
24-0-3	163	17.0	22.0	12.6	7.33		+
24-0-5	166	14.8	22.0	10.2	7.38		+
24-0-15	164	15.0	23.0	8.4	7.39		+
49-0-2		14.8	19.0	12.2	7.25		+
49-0-7		14.2	19.0	>15	7.21		+
49-0-13		14.8	19.0	>15	7.23		+
100-0-10	170	15.4	22.0	13.4	7.36	6.9	+
100-0-11	158	14.4	22.0	13.0	7.36	3.7	+

TABLE D-6. REDOX, DISSOLVED OXYGEN, pH, AND VIABILITY DATA FOR ANAEROBIC MICROCOSMS

Sample #	Redox mV	Volume of Sample Analyzed, ml	Temp °C	DO ppm	pH	H_2O_2 ppm	Bacterial Growth
1-A-1		14.4	23.0	2.8	8.01		+
1-A-6		14.4	22.5	2.6	7.91		+
1-A-15		16.4	24.0	2.6	8.19		+
25-A-2	-160	18.8	25.0	1.4	7.26		+
25-A-7	-147	16.6	25.0	1.6	7.29		+
25-A-8	-146	15.6	25.0	1.4	7.37		+
50-A-4		16.2	20.0	4.8	6.68		+
50-A-11		16.4	20.0	3.2	6.87		+
50-A-12		16.8	20.0	3.1	6.81		+
101-A-5	-142	13.6	21.0	3.2	7.52		+
101-A-9	-146	15.6	22.0	3.4	7.59		+
101-A-13	-156	14.0	22.0	3.4	7.54		+

TABLE D-7. REDOX, DISSOLVED OXYGEN, pH, AND VIABILITY DATA FOR GAMMA-IRRADIATED, ANAEROBIC STERILE CONTROL MICROCOSMS

Sample #	Redox mV	Volume of Sample Analyzed, ml	Temp °C	DO ppm	pH	H_2O_2 ppm	Bacterial Growth
1-AS-7		15.2	23.0	3.0	7.94		-
1-AS-13		16.0	23.0	3.0	7.90		-
1-AS-15		15.6	23.0	3.1	7.93		-
25-AS-1	-59	16.2	25.0	1.6	7.45		-
25-AS-4	-63	17.0	25.0	1.4	7.57		-
25-AS-11	-23	20.4	25.0	1.4	7.48		-
50-AS-2		13.6	20.0	5.6	7.05		-
50-AS-8		16.0	20.0	5.0	7.09		-
50-AS-14		15.0	20.0	6.2	6.98		-
101-AS-6	-91	15.2	21.0	4.2	7.85		-
101-AS-9	-41	16.4	21.0	5.6	7.90		-
101-AS-12	-33	14.0	21.0	6.2	8.18		-

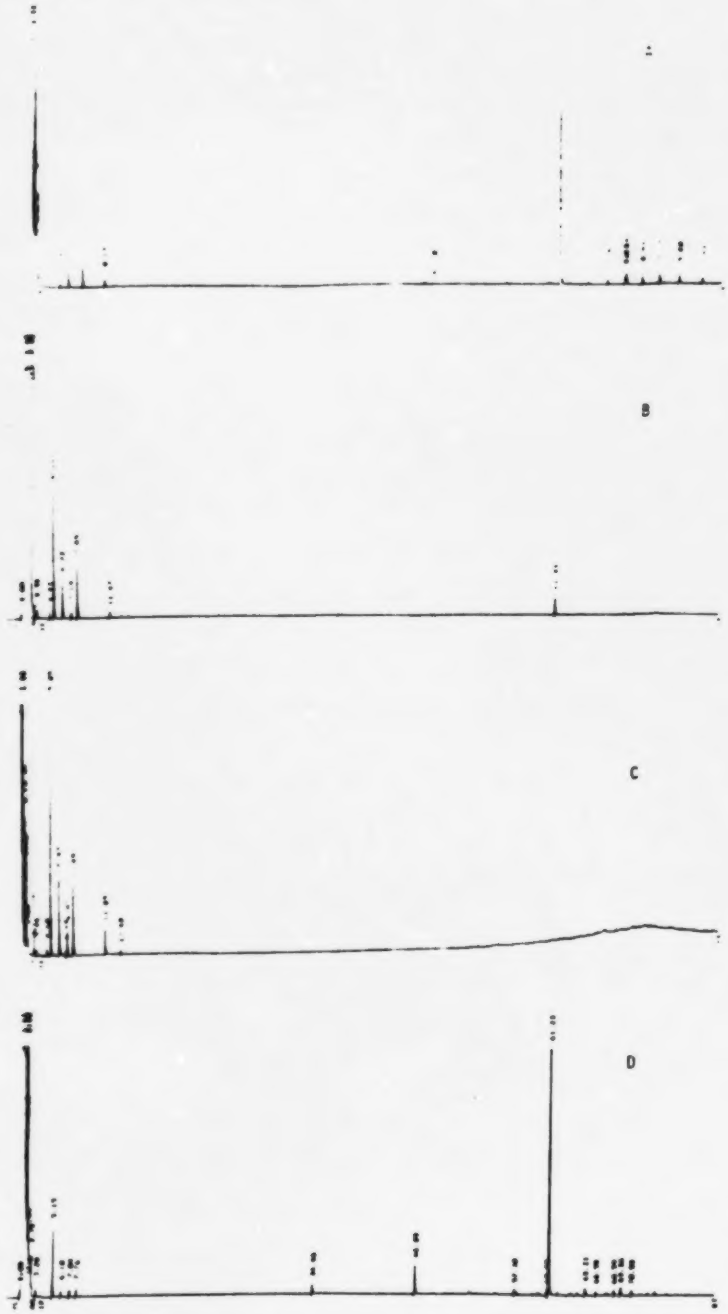

Figure D-1. FID-GC Chromatographic Profiles of Method Blanks Generated During Soil Extraction and Analysis. Chromatogram A: Day 1; Chromatogram B: Day 25; Chromatogram C: Day 50; and Chromatogram D: Day 100.

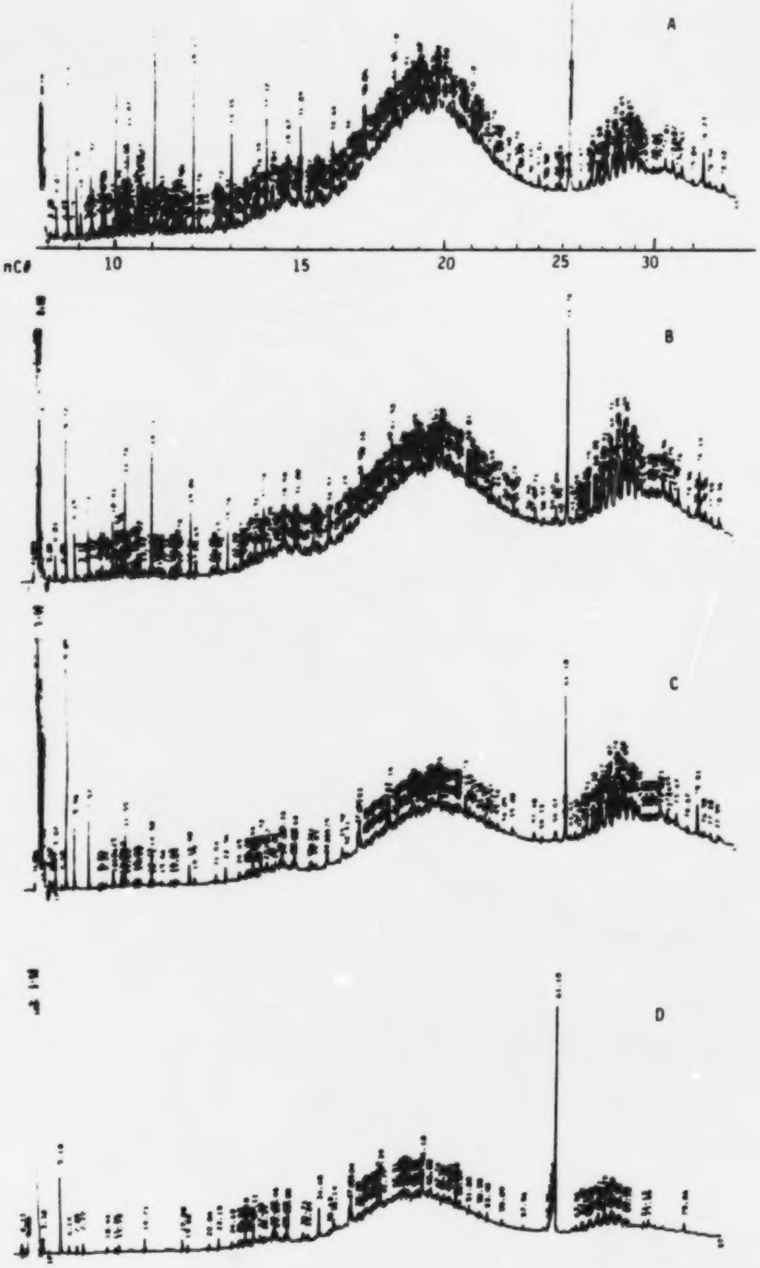

Figure D-2. FID-GC Chromatographic Profiles of Soil Extracts From Hydrogen Peroxide-Treated Aerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49; Chromatogram D: Day 100.

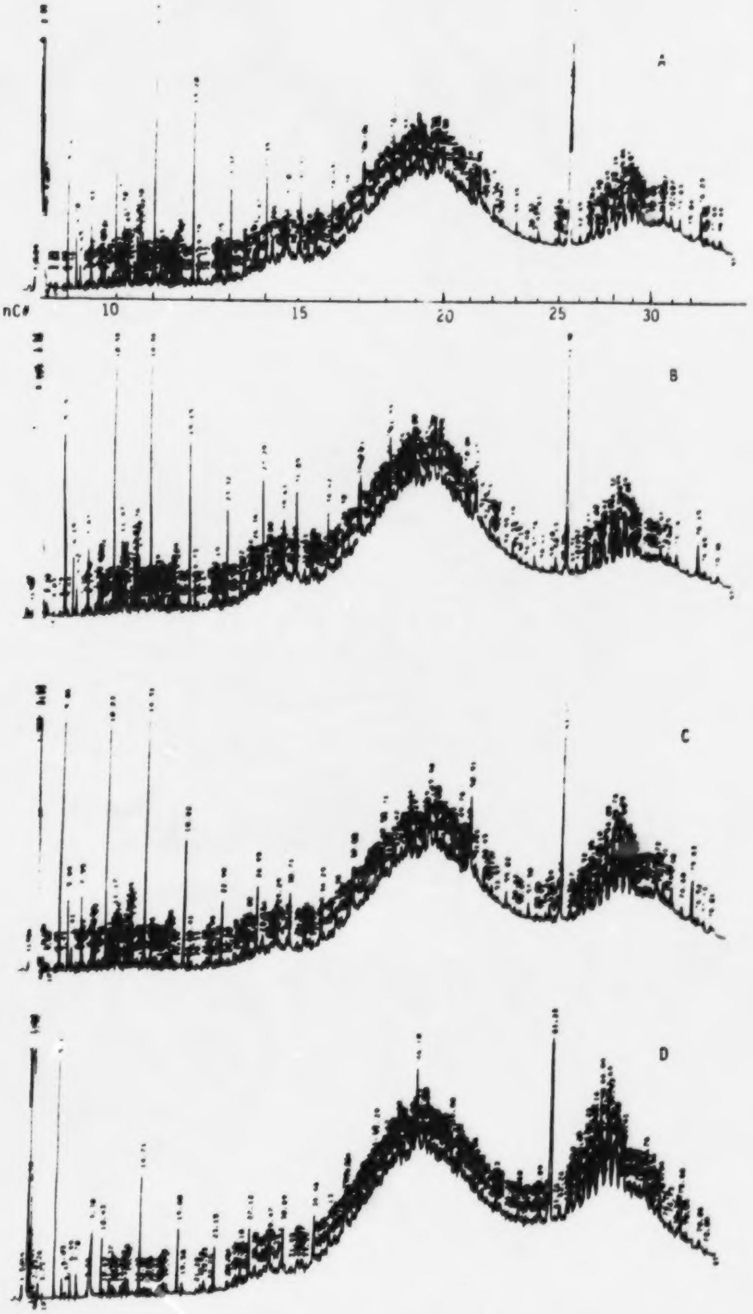

Figure D-3. FID-GC Chromatographic Profiles of Soil Extracts From Gamma-Irradiated Hydrogen Peroxide-Treated, Aerobic Sterile Control Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49; Chromatogram D: Day 100.

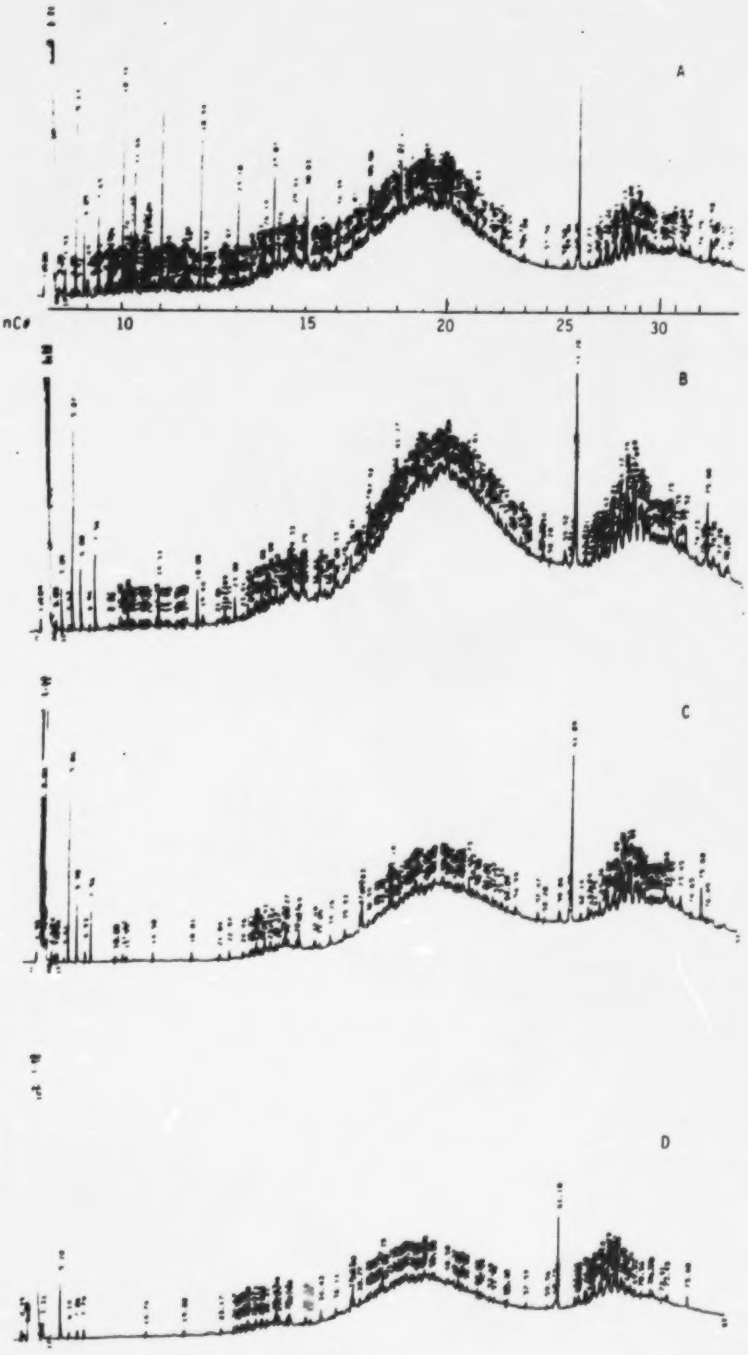

Figure D-4. FID-GC Chromatographic Profiles of Soil Extracts from Oxygen-Treated Aerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49; Chromatogram D: Day 100.

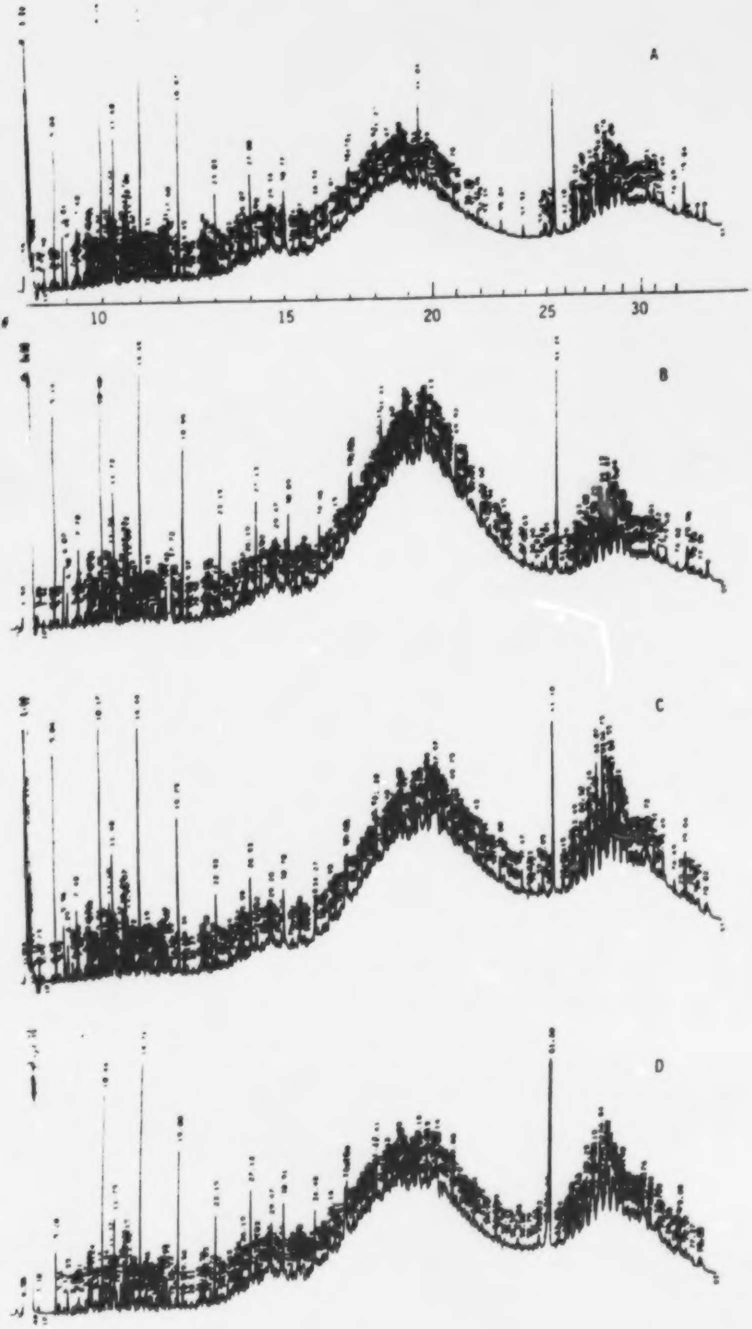

Figure D-5. FID-GC Chromatographic Profiles of Soil Extract From Anaerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 25; Chromatogram C: Day 50; Chromatogram D: Day 101.

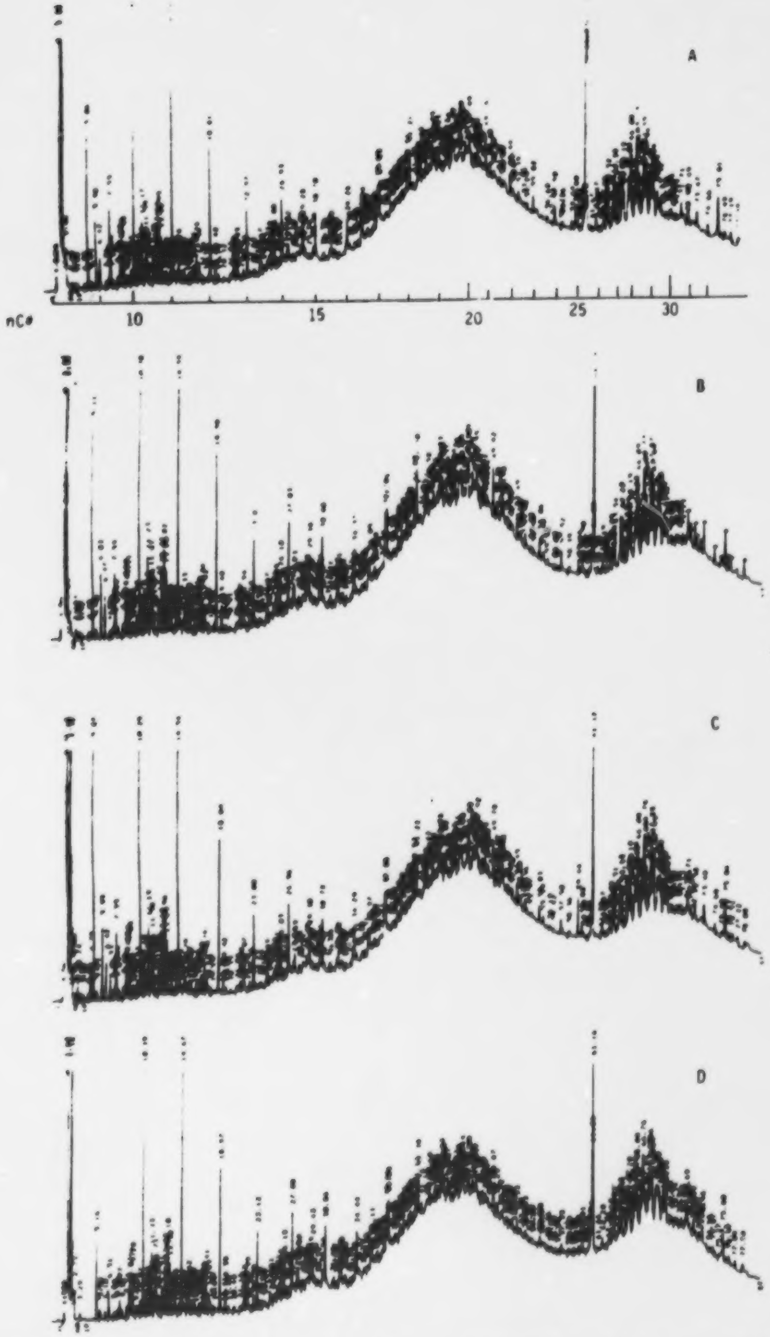

Figure D-6. FID-GC Chromatographic Profiles of Soil Extracts from Gamma-Irradiated, Anaerobic Sterile Control Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 25; Chromatogram C: Day 50; Chromatogram D: Day 101.

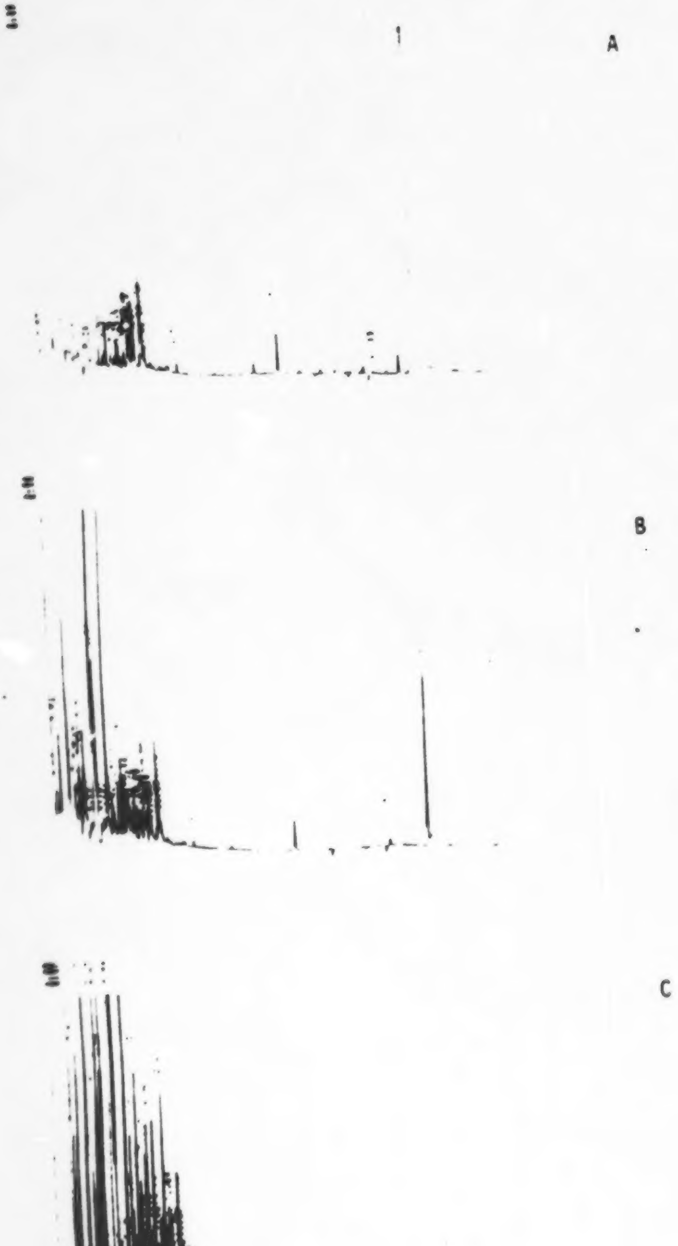

Figure D-7. Capillary ECD-GC Chromatographic Profiles of Method Blanks Generated During Soil Extraction and Analysis. Chromatogram A: Day 1; Chromatogram B: Day 25; Chromatogram C: Day 50.

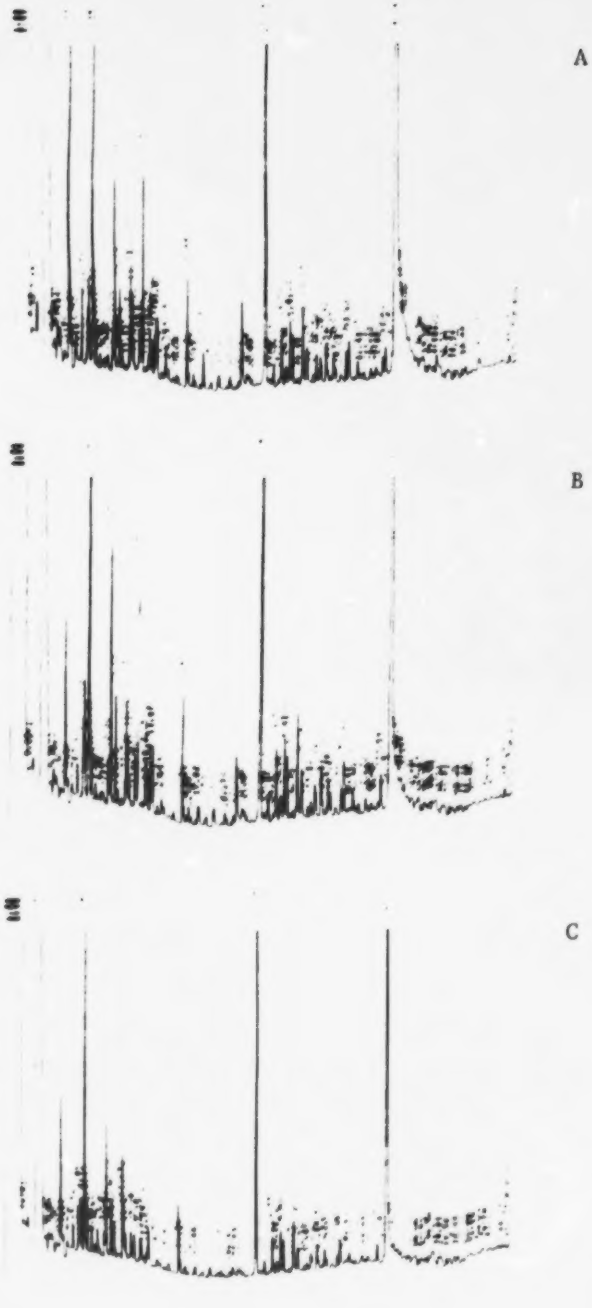

Figure D-8. Capillary ECD-GC Chromatographic Profiles of Soil Extracts From Hydrogen Peroxide-Treated, Aerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49.

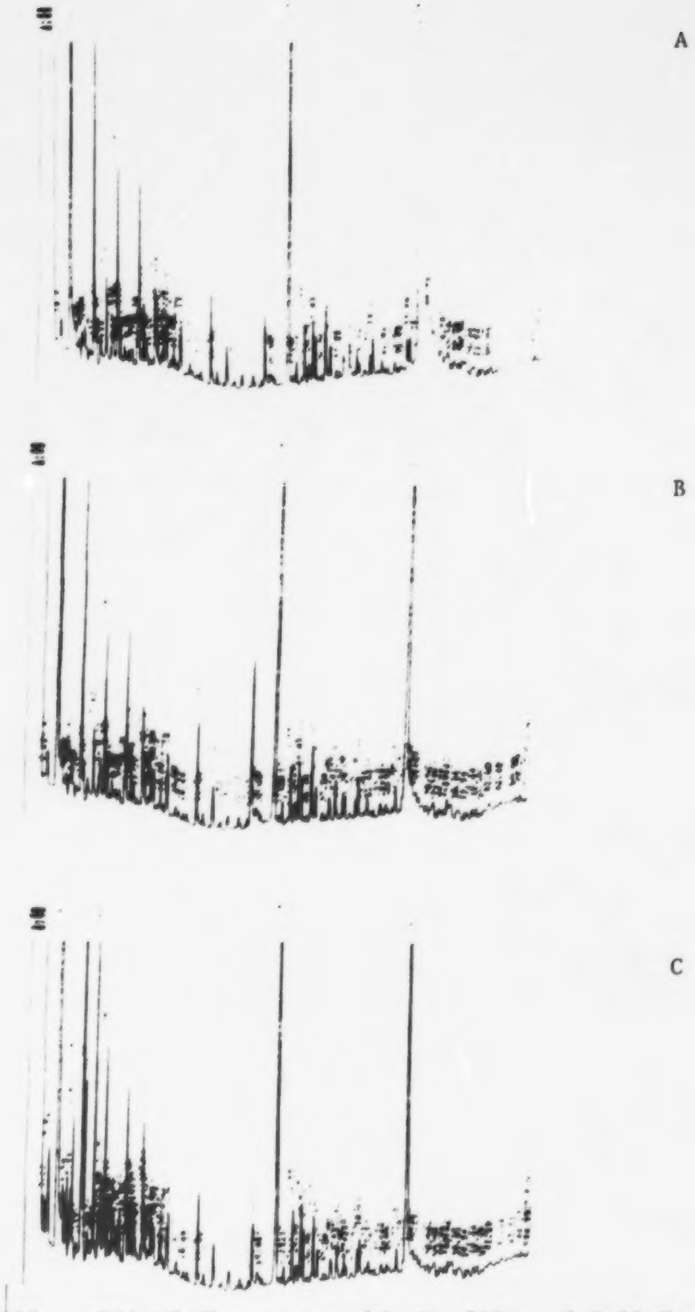

Figure D-9. Capillary ECD-GC Chromatographic Profiles of Soil Extracts From Gamma-Irradiated, Hydrogen Peroxide-Treated, Aerobic Sterile Control Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49.

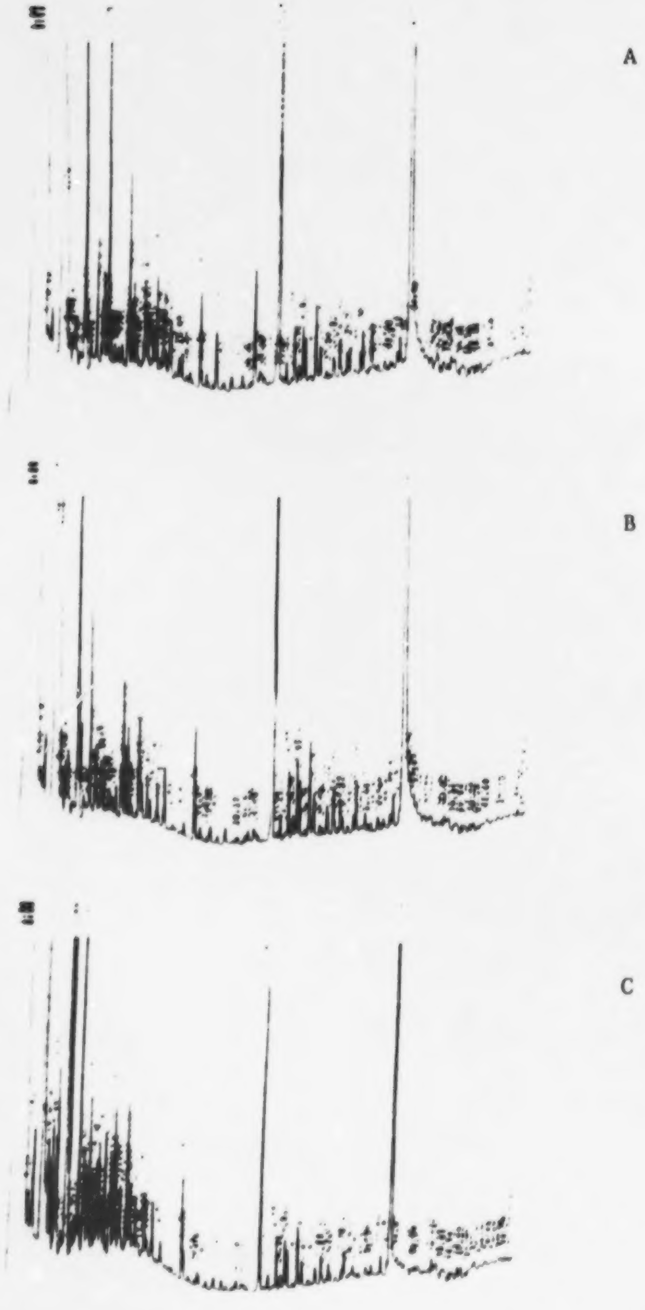

Figure D-10. Capillary ECD-GC Chromatographic Profiles of Soil Extracts From Oxygen-Treated Aerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 24; Chromatogram C: Day 49.

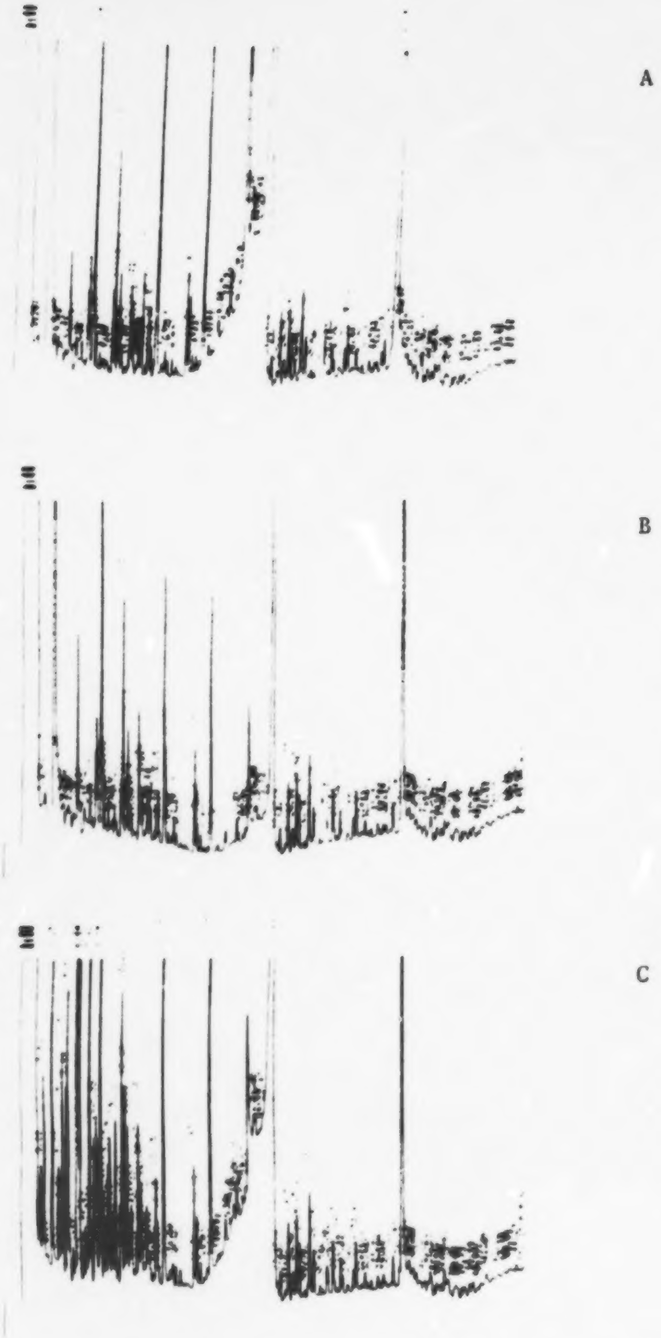

Figure D-11. Capillary ECD-GC Chromatographic Profiles of Soil Extracts From Anaerobic Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 25; Chromatogram C: Day 50.

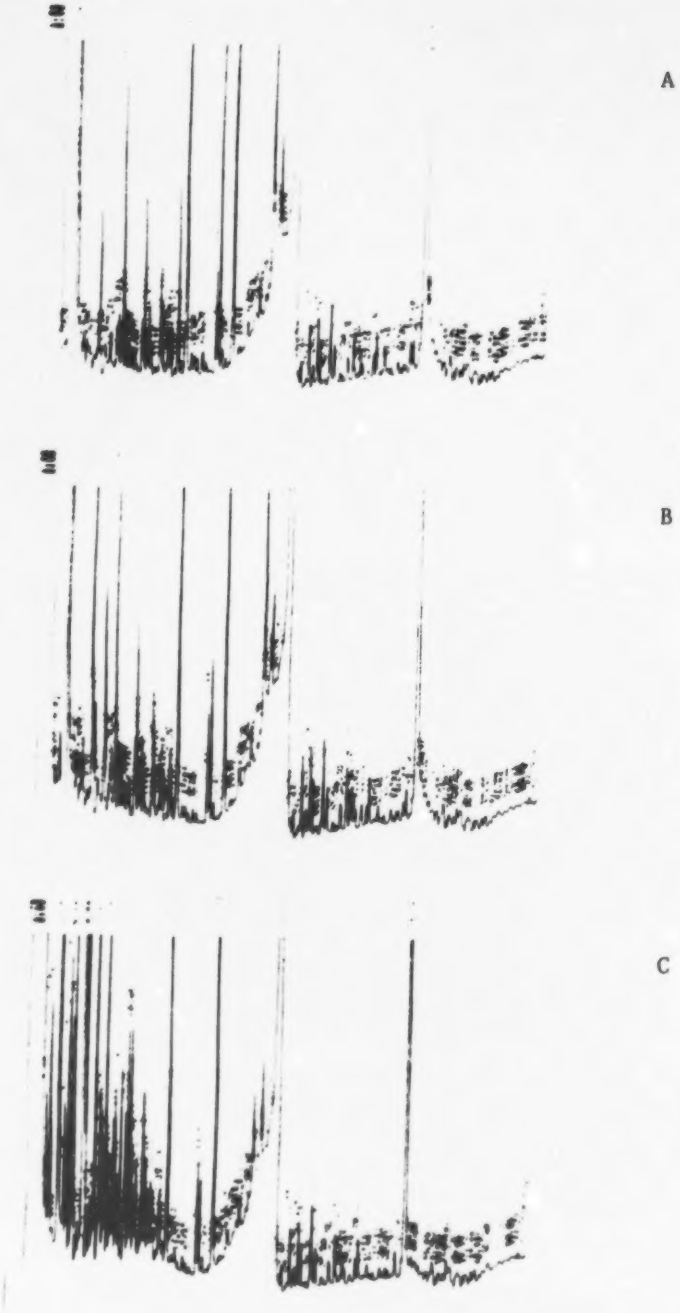

Figure D-12. Capillary ECD-GC Chromatographic Profiles of Soil Extracts from Gamma-Irradiated, Anaerobic Sterile Control Microcosms. Chromatogram A: Day 1; Chromatogram B: Day 25:; Chromatogram C: Day 50.

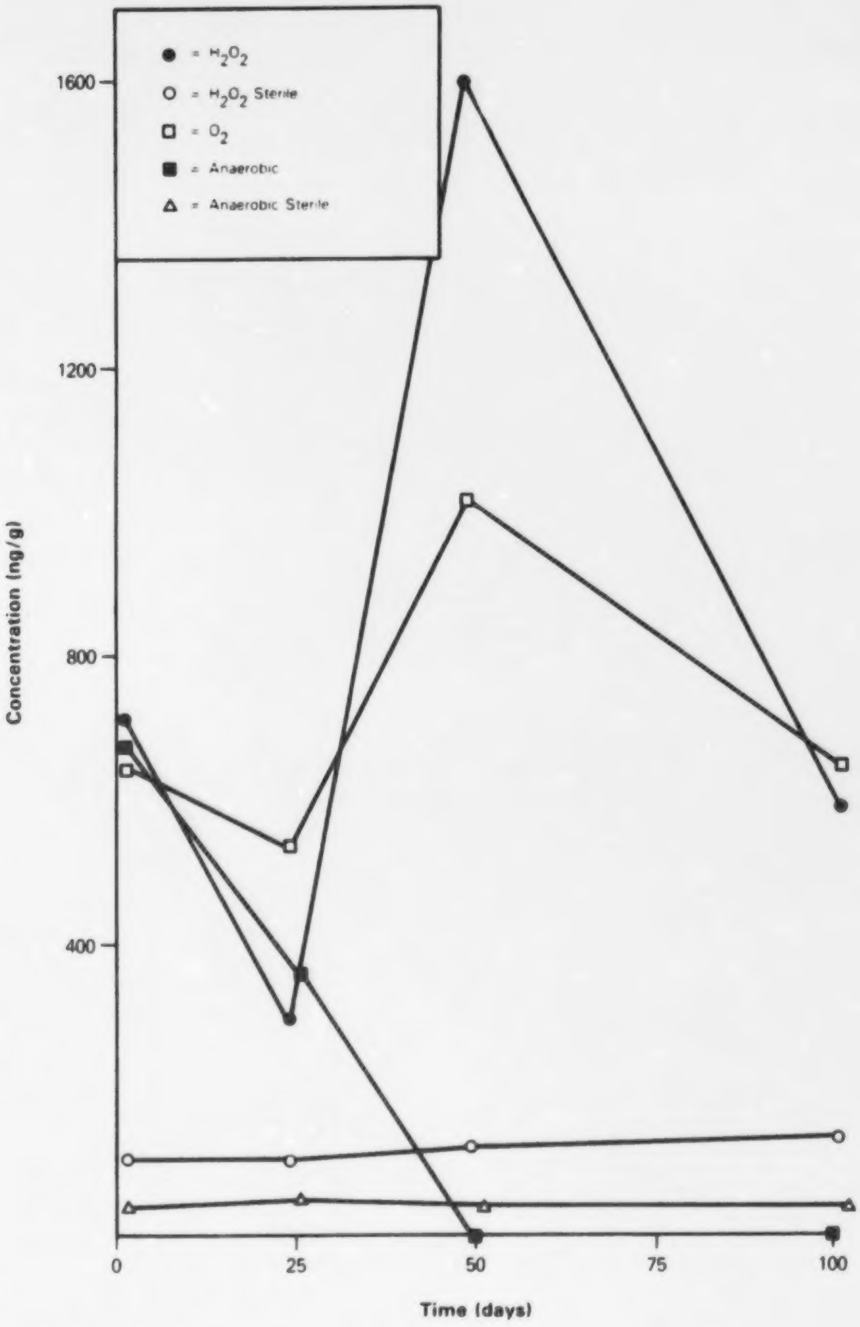

Figure D-13. Tetrachloroethene (PCE) Concentration Versus Time

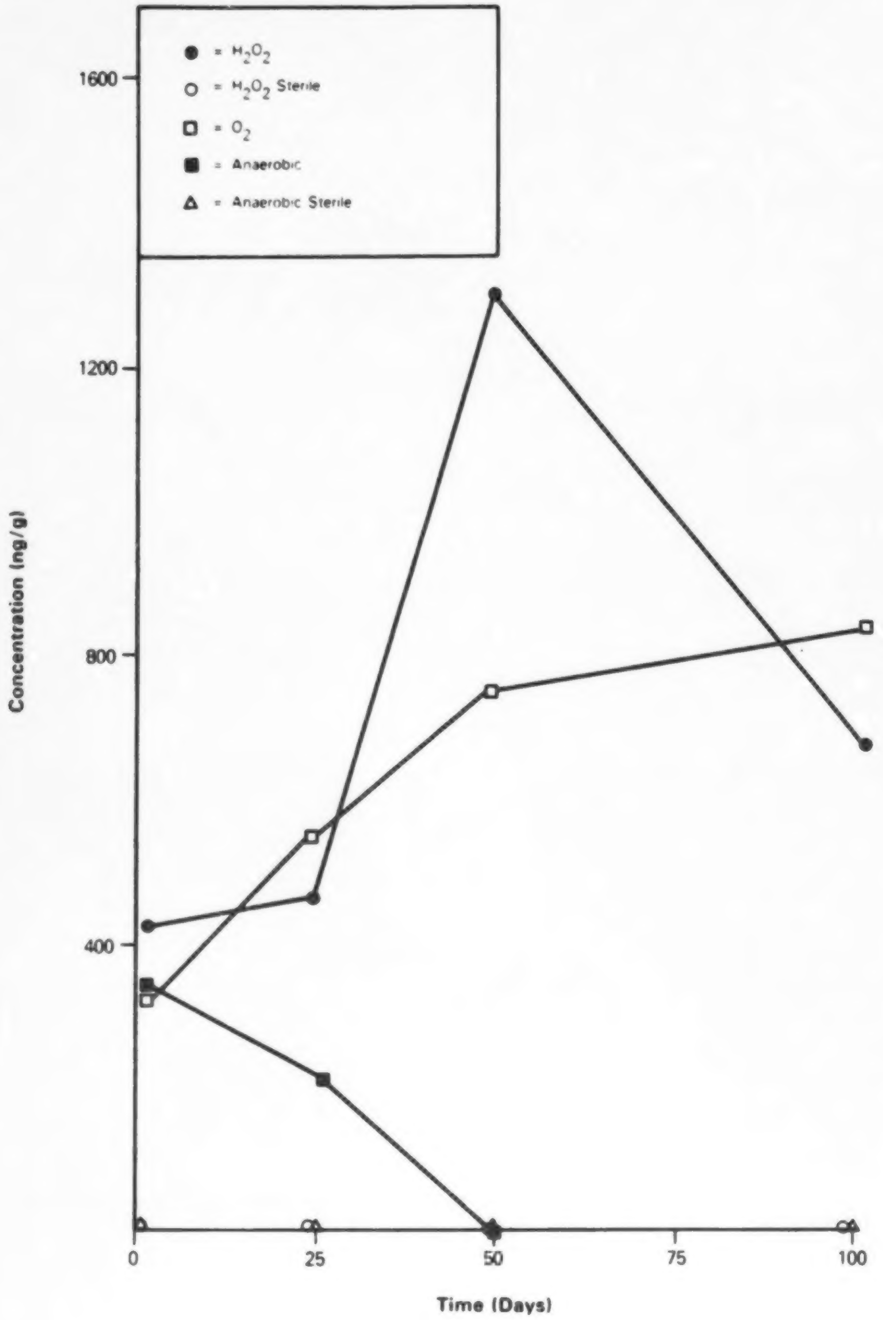

Figure D-14. Trichloroethene (TCE) Concentration Versus Time

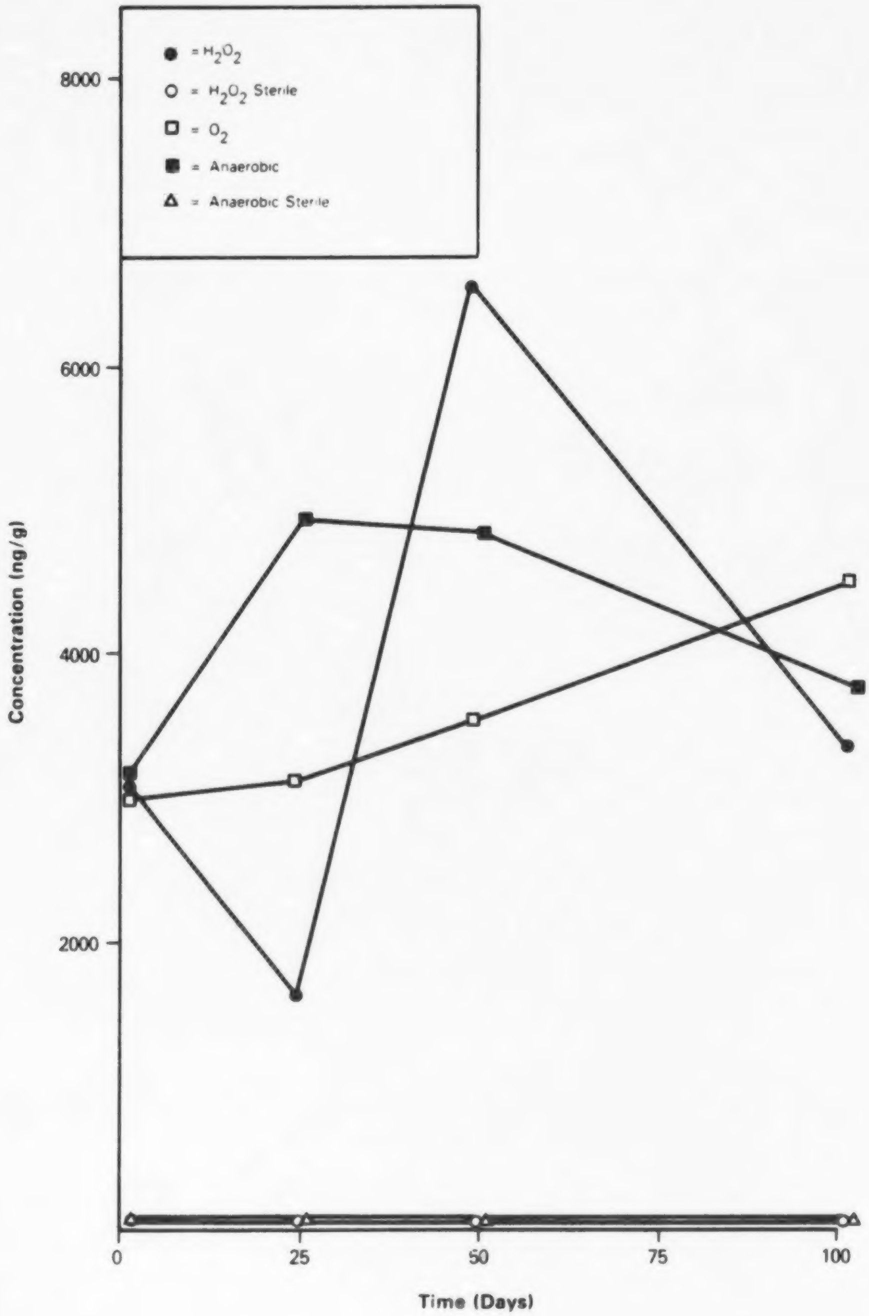

Figure D-15. Trans-1,2-Dichloroethene (Trans-1,2-DCE) Concentration Versus Time

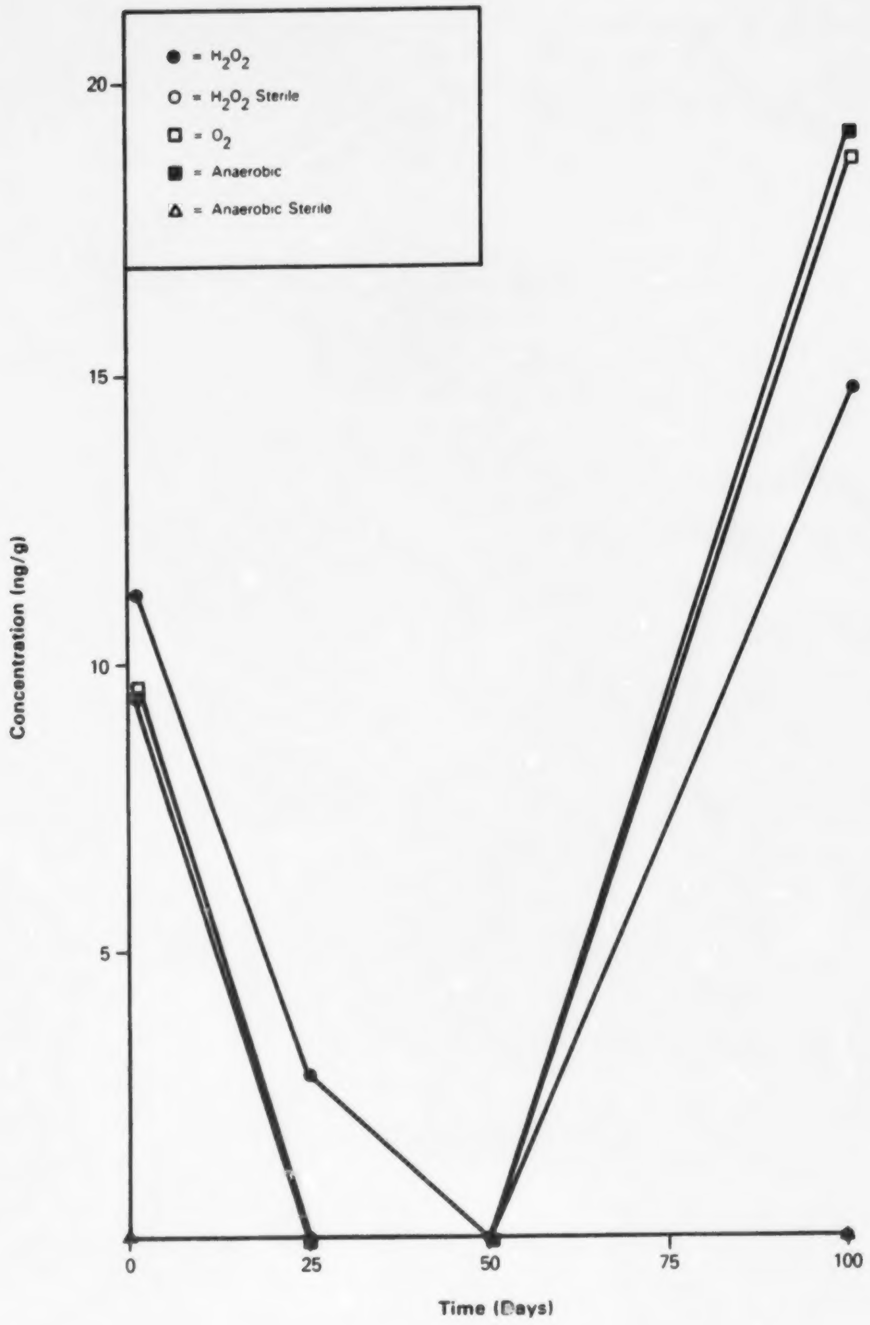

Figure D-16. 1,1-Dichloroethene (1,1-DCE) Concentration Versus Time

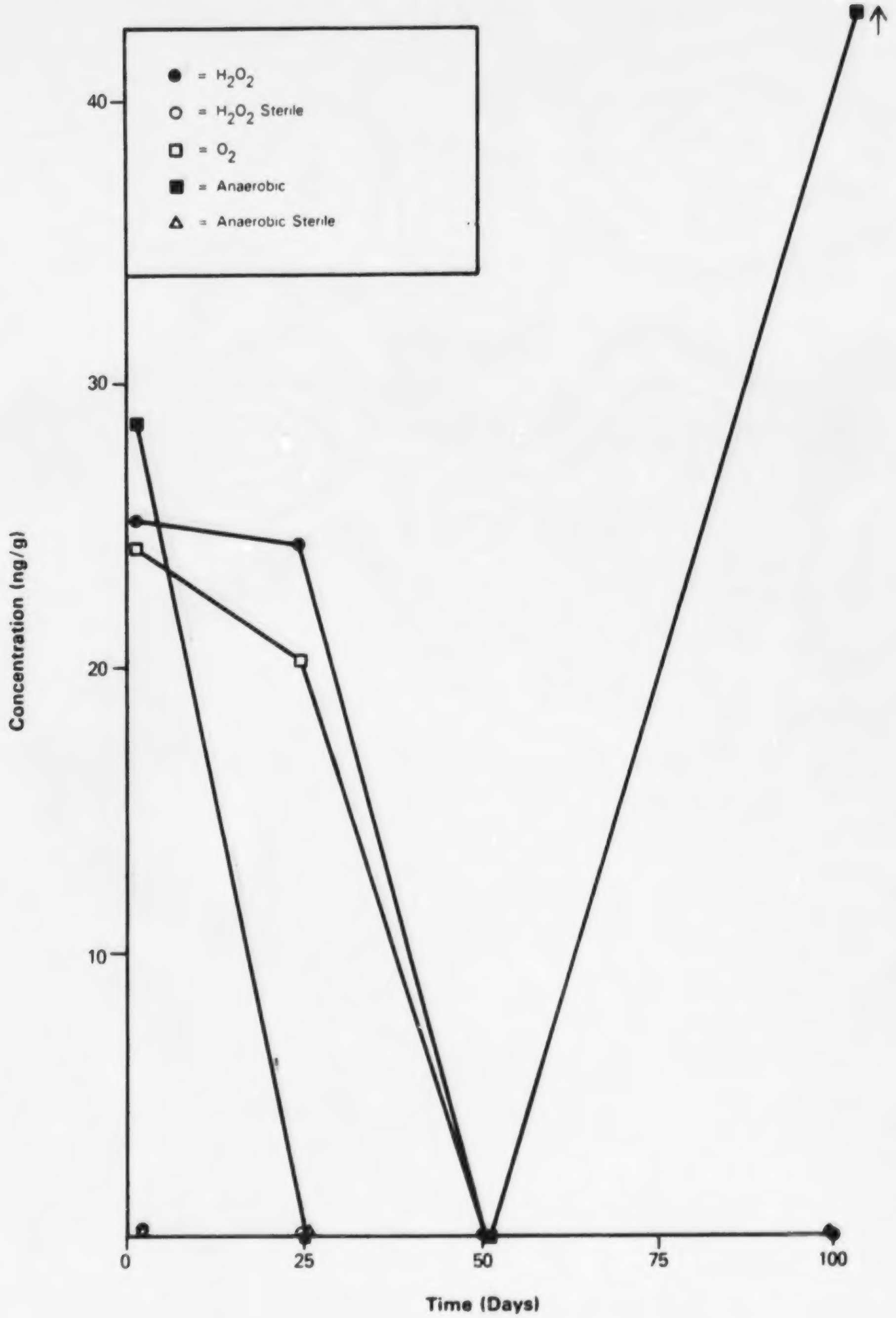

Figure D-17. 1,1-Dichloroethane (1,1-DCA) Concentration Versus Time

RAW AND STATISTICAL DATA FROM GC/MS VOLATILE ORGANIC ANALYSIS OF HOMOGENEOUS MICROCOSM SOIL/WATER SAMPLES

Microcosms were identified by an X-Y-Z code throughout this project where

X = the day of sacrifice (1, 24, 25, 49, 50, 100, or 101)

Y = microcosm type as follows:

H = Hydrogen Peroxide Treated Aerobic Microcosm

HS = Gamma-Irradiated, Hydrogen Peroxide Treated, Aerobic Sterile Control Microcosm

O = Oxygen Treated Aerobic Microcosm

A = Anaerobic Microcosm

AS = Gamma-Irradiated, Anaerobic Sterile Control Microcosm

Z = Microcosm number (Fifteen microcosms of each type were assembled and numbered 1-15. Sacrificed systems were selected randomly.)

Statistical data are given with means and coefficients of variation.

VOA Analysis of Day 1 Samples

Raw Data

	Sample #														
	1-H-2	1-H-6	1-H-10	1-HS-6	1-HS-9	1-HS-15	1-0-1	1-0-12	1-0-14	1-A-1	1-A-6	1-A-15	1-AS-7	1-AS-13	1-AS-15
Compound															
DCM, ppb	33	71	54	102	103	35	43	46	26	36	30	35	16	37	9
Acetone	361	349	199	325	328	389	393	403	331	450	444	322	145	271	144
1,1-DCE	10	12	15	—	—	—	9	12	7	9	11	6	—	—	—
1,1-DCA	24	25	27	—	—	—	22	28	21	25	30	16	—	—	—
trans-1,2-DCE	3229	2940	3215	8	8	6	2856	3296	2869	3126	3406	1894	9	15	8
Chloroform	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
2-Butanone	11	11	8	17	18	22	9	7	8	14	12	17	23	44	23
1,1,1-TCA	22	24	31	—	—	—	20	27	20	24	28	9	—	—	—
TCE	429	380	453	4	4	3	330	395	348	359	374	177	3	2	2
Benzene	3	3	3	—	12	—	3	2	2	2	1	2	—	—	—
PCE	750	621	778	78	85	68	565	710	614	667	661	317	27	25	21
Toluene	6	7	8	—	—	—	4	6	4	8	9	8	2	2	1
Chlorobenzene	8	8	8	2	1	2	9	8	5	11	13	10	4	4	3
Ethyl-Benzene	1	2	3	—	—	—	1	1	0.4	1	2	2	—	—	—
Chloroethane	—	—	—	—	—	—	—	—	—	—	—	—	14	15	14
Carbon Disulfide	—	—	—	—	—	—	—	—	—	—	—	—	43	53	67

— = None detected

VOA Analysis of Day 24/25 Samples

Raw Data

	Sample #													
Compound	24-H-1	24-H-14	24-H-15	24-HS-2	24-HS-13	24-0-3	24-0-5	24-0-15	25-A-2	25-A-7	25-A-8	25-AS-1	25-AS-4	25-AS-11
DCM, ppb	3	11	8	2	1	8	—	—	—	—	—	—	—	—
Acetone	—	—	88	—	—	45	—	—	—	—	—	3191	—	3522
1,1-DCE	2	5	3	—	—	2	—	—	—	—	—	—	—	—
1,1-DCA	23	—	24	—	—	27	12	—	1284	—	—	—	—	—
trans-1,2-DCE	1771	1807	1824	9	6	1698	2335	5267	5776	4636	4452	31	19	24
Chloroform	—	—	—	5	5	6	—	—	—	—	—	—	—	—
2-Butanone	—	—	—	214	178	—	—	—	—	—	—	—	37	—
1,1,1-TCA	14	17	74	—	—	20	—	10	7	6	4	11	29	13
TCE	457	487	455	13	9	519	200	971	330	488	277	12	5	9
Benzene	1	1	1	—	—	1	—	1	1	1	—	—	0.5	—
PCE	277	298	282	80	62	295	284	1021	477	378	233	39	23	30
Toluene	—	—	—	—	—	—	—	—	—	5	—	—	—	—
Chlorobenzene	13	7	8	9	5	—	—	—	20	27	17	14	16	19
Vinyl Acetate	0.5	1	2	—	0.05	1	—	—	—	—	—	—	—	—
Vinyl Chloride	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—

— = None detected

VOA Analysis of Day 49/50 Samples

Raw Data

	Sample #													
	49-H-4	49-H-7	49-H-12	49-HS-1	49-HS-14	49-O-2	49-O-7	49-O-13	50-A-4	50-A-11	50-A-12	50-AS-2	50-AS-8	50-AS-14
Compound														
DCM, ppb	—	—	—	3	19	4	3	—	—	—	—	—	—	—
1,1-DCE	—	—	—	—	—	3	—	—	—	—	—	—	—	—
1,1-DCA	—	—	—	—	—	610	—	—	—	—	1089	—	—	—
trans-1,2-DCE	6058	6735	6934	17	14	2678	3109	4478	4647	5173	4669	43	11	20
2-Butanone	—	—	—	—	15	—	—	—	16	—	—	40	3	4
1,1,1-TCA	47	29	14	6	5	12	17	29	8	9	6	6	11	30
TCE	1739	1171	1018	6	7	695	721	875	—	1	—	5	2	4
Benzene	2	—	1	—	—	—	—	—	—	1	1	—	—	—
PCE	1640	1617	1454	109	112	870	860	1289	—	1	—	26	25	26
Toluene	—	—	—	—	—	—	—	—	—	3	—	—	—	—
Chlorobenzene	—	—	—	11	4	—	—	—	18	22	14	13	10	14

— = None detected

VOA Analysis of Day 100/101 Samples

Raw Data

	Sample #												
	100-H-5	100-H-9	100-H-11	100-HS-11	100-HS-12	100-0-10	100-0-11	101-A-5	101-A-9	101-A-13	101-AS-6	101-AS-9	101-AS-12
Compound													
DCM, ppb	13	18	11	—	—	18	14	—	—	—	—	--	23
Acetone	—	—	25	--	—	—	--	--	—	—	—	—	—
1,1-DCE	15	10	10	—	—	18	15	17	19	19	—	—	--
1,1-DCA	995	—	26	—	—	—	1053	—	910	969	—	—	--
trans-1,2-DCE	3962	4754	1197	21	21	4632	4218	4072	3572	3768	41	29	—
Chloroform	—	—	3	3	—	—	--	--	—	—	2	--	--
2-Butanone	—	—	27	30	21	—	—	—	—	—	13	19	18
1,1,1-TCA	21	26	16	3	8	60	30	13	16	22	12	6	10
TCE	684	781	565	14	9	859	764	0.5	—	--	12	7	—
Benzene	3	2	3	--	—	2	2	2	2	2	—	—	--
PCE	590	673	519	155	95	668	593	2	1	1	43	33	6
Toluene	—	—	—	—	—	—	—	6	7	7	3	—	--
Chloro-benzene	0.03	3	9	9	7	—	—	31	27	27	25	22	4
Ethylbenzene	—	—	—	—	—	—	—	1	2	2	1	—	—
Carbon Disulfide		—	—	—	—	—	—	--	--	—	16	7	2
Vinyl Chloride	—	—	—	—	—	—	—	—	30	26	—	—	—
1,1,2-TCA	—	—	5	—	—	20	—	--	1	—	—	—	—
Carbon Tetrachloride	3	3	—	—			—	--	—	—	—	—	—

— = None detected

Statistical Analysis of VOA Sample Results

Microcosm Type	H	H	H	H	HS	HS	HS	HS	O	O	O	O	A	A	A	A	AS	AS	AS	AS
Sample Day	1	26	49	100	1	26	49	100	1	26	49	100	1	25	50	101	1	25	50	101
DCM, ppb	55±16	7±58	—	14±26	80±49	2±71	11±101	—	30±28	3±154	4±18	16±18	34±9	—	—	—	21±69	—	—	—
Acetone	101±10	—	—	—	967±10	—	—	—	176±10				467±1	—	—	—	187±39	3357±2	—	—
1,1-DCE	12±21	5±51	—	16±29	—	—	—	—	9±28			17±12	9±28	—	—	18±6	—	—	—	—
1,1-DCA	25±6	20±3	—	—	—	—	—	—	24±16	20±53			20±13	—	—	930±3	—	—	—	—
trans-1,2-DCE	1128±5	1801±2	6576±7	1938±57	7±16	8±27	16±11	21±0	1007±8	3100±61	1622±27	6625±7	3266±6	4955±14	4830±6	3797±8	11±34	25±24	25±66	35±24
Chloroform	—	—	—	—	—	5±0	—	5±0												
2-Butanone	10±17	—	—	—	19±16	196±11	—	26±25	8±13				14±18	—	—	—	30±40	—	16±132	17±19
1,1,1-TCA	26±10	55±97	10±55	21±24	—	—	6±12	6±59	22±10	15±67	19±66	39±11	26±11	6±25	8±19	17±27	—	18±55	16±79	9±34
TCE	421±9	444±4	1939±24	677±16	4±14	11±26	7±10	12±29	350±9	563±69	784±13	812±8	367±3	218±64	—	—	2±29	9±34	4±38	10±35
Benzene	5±0	1±0	2±35	3±14	—	—	—	—	2±29	1±0	—	2±0	2±29	1±0	1±0	2±0	—	—	—	—
PCE	716±12	286±4	1577±7	514±13	77±11	71±18	111±2	125±36	630±12	533±79	1036±24	611±8	665±0.4	363±34		1±58	24±13	31±26	26±2	38±19
Toluene	7±14	—	—	—	—	—	—	—	5±23	—	—	—	8±7	—	—	7±8	2±29	—	—	—
Chlorobenzene	8±0	9±36	—	4±114	2±29	7±40	8±62	8±18	7±30	—	—	—	11±14	21±24	18±22	28±8	4±14	16±16	12±17	28±9
Ethylbenzene	2±50	—	—	—	—	—	—	—	1±83	—	—	—	2±29	—	—	2±29	—	—	—	—
Chloroethane	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14±4	—	—	—
Carbon Disulfide	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	54±22	—	—	8±89
Vinyl chloride	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28±10	—	—	—	—
Carbon tetrachloride	—	—	—	5±0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Data reported as mean (ppb) ± coefficient of variation (%).
— : None detected

GC/MS: FID-GC CORRELATIONS AND STATISTICAL EVALUATION

Microcosms were identified by an X-Y-Z code throughout this project where

X = the day of sacrifice (1, 24, 25, 49, 50, 100, or 101)

Y = microcosm type as follows:

H = Hydrogen Peroxide Treated Aerobic Microcosm

HS = Gamma-Irradiated, Hydrogen Peroxide Treated, Aerobic Sterile Control Microcosm

O = Oxygen Treated Aerobic Microcosm

A = Anaerobic Microcosm

AS = Gamma-Irradiated, Anaerobic Sterile Control Microcosm

Z = Microcosm number (Fifteen microcosms of each type were assembled and numbered 1-15. Sacrificed systems were selected randomly.)

Statistical data are given with means and coefficients of variation.

N-ALKANES

n-Alkanes are identified by the nC# system where the nC# is the number of carbon atoms in the alkane of interest.

For example, nC-9 is nonane, nC-10 is decane, etc. Concentrations for raw data are given in µg/g dry weight while statistical data are given in ng/g dry weight.

H Systems

n-C#	RT	1-H-2	1-H-6	1-H-10	24-H-1	24-H-14	24-H-15	49-H-4	49-H-7	49-H-12	100-H-5	100-H-9	100-H-11
9	6.63	.053	.085	.090	0	0	0	0	0	0	0	0	0
10	10.54	.556	.952	.965	.099	.152	.168	.049	.043	.048	0	—	0
11	14.34	.890	1.61	1.64	.266	.338	.398	.128	.096	.155	0	—	0
12	19.17	.880	.760	.824	.158	.187	.223	.095	.062	.110	0	0	.004
13	23.34	.230	.433	.486	.111	.128	.154	.079	.050	.081	.007	0	.005
14	27.32	.295	.520	.593	.156	.172	.215	.120	.082	.132	.012	.060	.010
15	31.08	.156	.257	.288	.106	.109	.141	.072	.053	.081	.014	.069	.010
16	34.66	.207	.334	.168	.137	.145	.080	.089	.024	.106	.020	.092	.033
17	38.06	.165	.259	.274	.114	.121	.131	.075	.055	.080	.020	.057	.005
18	41.30	.117	.164	.167	.083	.086	.086	.065	.039	.061	.012	0	.006
19	44.27	.032	.062	.053	.030	.036	.061	.038	.024	.023	.007	0	.005
20	47.18	.026	.051	.054	.037	.039	.040	.035	.027	.037	.010	0	.007
21	50.11	.184	.242	.264	.208	.215	.265	.107	.102	.132	.024	0	.016
22	52.78	.071	.089	.106	.063	.071	.085	.028	.027	.037	.028	0	.006
23	55.34	.059	.071	.093	.050	.057	.079	.021	.020	.029	.013	0	0
24	57.81	.050	.067	.068	.034	.063	.076	.024	.022	.029	.046	0	.007
25	60.19	.065	.055	.067	.053	.090	.163	.022	.023	.038	.038	0	0
26	62.48	.042	.063	.065	0	.052	.057	.027	0	.069	.017	0	0
27	64.69	.198	.229	.214	.181	.285	.307	.109	.116	.142	.067	0	.019
28	66.82	.126	.100	.061	.048	.167	.171	.079	.063	.082	.029	.126	.007
29	68.83	.060	.048	.068	.053	.107	.120	.027	.038	.035	.010	0	0
30	70.66	.074	0	.057	0	.058	.031	.033	.019	.069	.010	0	.005
31	72.81	.105	.074	.099	.085	.149	.159	.065	.061	.061	.027	0	.017
32	75.04	.086	0	0	0	.071	.079	.034	.021	.035	.016	0	0
Pristane		.198	.295	.305	.204	.191	.237	.128	.103	.136	.033	.101	.014
Phytane		.259	.411	.466	.264	.320	.360	.161	.153	.177	.036	.111	.019

All concentrations are given in µg/g dry weight.
RT = FID-GC Retention Time

HS Systems

nC-#	1-HS-6	1-HS-9	1-HS-15	24-HS-13	49-HS-1	49-HS-14	100-HS-11	100-HS-12
9	.090	.086	.067	.077	.059	.065	0	0
10	1.102	.912	.721	.853	.654	.704	.012	.053
11	1.937	1.461	1.199	1.314	1.001	1.104	.031	.127
12	.904	.642	.554	.558	.426	.475	.020	.072
13	.551	.382	.366	.363	.270	.296	.017	.058
14	.556	.458	.366	.417	.302	.338	.024	.081
15	.267	.270	.218	.262	.157	.201	.016	.063
16	.347	.306	.231	.285	.201	.216	.033	.096
17	.264	.261	.215	.225	.166	.153	.014	.020
18	.165	.179	.150	.162	.087	.097	.009	.018
19	.039	.067	.077	.085	.048	.067	.004	.012
20	.061	.068	.037	.031	.026	.030	0	.008
21	.261	.329	.281	.268	.139	.160	.021	.047
22	.096	.117	.120	.090	.067	.056	.008	.020
23	.075	.111	.107	.088	.062	.067	.009	.012
24	.069	.070	.086	.061	.060	.055	.015	0
25	.055	.071	.084	.078	.038	.067	.036	.009
26	.069	.087	.090	.061	.027	.026	.012	.026
27	.256	.291	.240	.209	.128	.172	.031	.055
28	.061	.085	.130	.124	.076	.116	.027	.032
29	.068	.089	.069	.062	.036	.040	.020	.020
30	.057	.078	0	.063	.020	.019	.024	.013
31	.099	.126	.095	.099	.089	.137	.053	.053
32	0	.093	.062	0	.053	.070	.024	.024
Pristane	.303	.282	.252	.296	.169	.186	.015	.036
Phytane	.477	.357	.383	.410	.242	.240	.027	.099

All concentrations are given in μg/g dry weight.

0 Systems

n-C#	1-0-1	1-0-12	1-0-14	24-0-3	24-0-5	24-0-15	49-0-2	49-0-7	49-0-13	100-0-10	100-0-11
9	.058	.046	.044	0	0	0	0	0	0	0	0
10	.714	.594	.583	.028	0	0	0	0	0	0	—
11	1.364	1.188	1.253	.144	.080	.108	.046	0	0	0	--
12	.660	.598	.652	.132	.073	.093	.055	.033	0	0	0
13	.405	.356	.400	.043	.057	.068	.048	.036	0	0	0
14	.434	.379	.384	.134	.092	.111	.089	.069	0	.008	0
15	.269	.235	.231	.076	.048	.055	.044	.044	.017	.007	0
16	.164	.231	.173	.131	.032	.024	.030	.033	0	.027	0
17	.230	.213	.232	.092	.047	.070	.055	.058	0	.008	.038
18	.163	.123	.167	.049	.024	.043	.032	.037	0	.007	0
19	.092	.105	.100	.023	.029	.031	.026	.016	0	.003	0
20	.042	.061	.066	.031	.027	.021	.017	.030	0	.005	0
21	.191	.261	.255	.151	.131	.132	.072	.074	.022	.017	0
22	.050	.064	.081	.039	.028	.040	.025	.023	0	.007	0
23	.030	.064	.067	.025	.036	.060	.018	.018	0	.008	0
24	.035	.052	.052	.031	.024	.087	.024	.018	0	.005	0
25	.051	.089	.041	.059	.044	.053	.051	.015	0	.006	0
26	0	.054	.036	.051	.019	.040	.018	.014	0	.016	0
27	.172	.261	.242	.118	.106	.137	.068	.047	.023	.022	.064
28	.102	.139	.140	.044	.068	.110	.030	.052	.000	.025	.060
29	.031	.039	.096	.066	.073	.045	.025	.049	0	.039	.051
30	.075	.054	.051	.062	.053	.064	.030	.038	0	.018	0
31	.090	.107	.125	.094	.091	.163	.067	.060	.030	.079	0
32	.038	.048	.074	.037	.034	.075	.037	.025	0	.025	0
Pristane	.292	.279	.277	.187	.119	.127	.105	.112	.036	.009	.076
Phytane	.364	.335	.384	.206	.214	.179	.192	.139	.052	.030	.078

All concentrations are given in ug/g dry weight.

A Systems

n-C#	1-A-1	1-A-6	1-A-15	25-A-2	25-A-7	25-A-8	50-A-4	50-A-11	50-A-12	101-A-5	101-A-9	101-A-13
9	.039	.090	.043	.084	.121	.028	.069	.109	.077	.027	.480	0
10	.473	.907	.404	.805	1.187	.265	.594	.941	.792	.295	.464	.065
11	.809	1.354	.629	1.257	1.770	.428	.887	1.398	1.232	.519	.798	.165
12	.344	.533	.260	.523	.738	.179	.370	.597	.493	.250	.372	.096
13	.196	.279	.145	.300	.395	.102	.215	.303	.263	.164	.237	.072
14	.208	.322	.155	.346	.437	.117	.244	.336	.292	.209	.287	.099
15	.115	.157	.087	.181	.220	.063	.114	.221	.182	.109	.200	.074
16	.132	.168	.061	.234	.283	.044	.146	.215	.061	.155	.219	.107
17	.113	.155	.088	.190	.237	.069	.106	.158	.120	.170	.108	.044
18	.071	.084	.066	.138	.143	.045	.069	.079	.075	.064	.079	.045
19	.053	.050	.038	.032	.049	.035	.042	.087	.066	.031	.034	.014
20	.026	.063	.015	.079	.075	0	.033	.061	.029	0	.031	.016
21	.134	.121	.112	.226	.199	.100	.115	.178	.186	.059	.073	.048
22	.046	.043	.035	.080	.073	.036	.037	.059	.072	.592	.523	.025
23	.032	.045	.023	.062	.065	.031	.022	.059	.070	0	0	.015
24	.031	.042	.021	.049	.062	.027	.022	.055	.041	0	.383	.017
25	.027	.038	.017	.074	.095	.023	.020	.052	.072	0	.032	0
26	0	.028	0	.022	.041	0	.014	.031	.029	0	.044	.022
27	.121	.194	.104	.193	.029	.114	.077	.170	.173	.046	.132	.064
28	.075	.096	.057	.092	*	.054	.044	.047	.050	.130	.160	.034
29	.031	.068	.034	.022	*	.023	.018	*	.051	0	0	.019
30	0	.024	.017	.043	*	0	0	*	.016	.042	.042	.019
31	.059	.083	.028	.082	*	0	.033	*	.119	0	.114	.065
32	0	.058	.025	.042	*	0	.020	*	.050	0	0	.018
Pristane	.131	.205	.113	.231	.268	.083	.105	.173	.140	.069	.118	.043
Phytane	.171	.259	.156	.349	.417	.111	.115	.298	.262	.068	.214	.104

* : No data; too many peaks on chromatograph.

All concentrations are given in µg/g dry weight.

AS Systems

n-C#	1-AS-7	1-AS-13	1-AS-15	25-AS-1	25-AS-4	24-AS-11	50-AS-2	50-AS-8	50-AS-14	101-AS-6	101-AS-9	101-AS-12
9	.073	.027	.033	.098	.120	.095	.119	.090	.089	.064	.063	0
10	.658	.261	.331	.935	1.064	.862	1.120	.827	.798	.716	.613	.062
11	.998	.382	.517	1.433	1.591	1.288	1.720	1.221	1.179	1.186	.902	.145
12	.407	.148	.221	.630	.668	.550	.729	.491	.487	.493	.364	.079
13	.219	.085	.135	.340	.360	.285	.373	.260	.260	.276	.215	.058
14	.242	.091	.165	.379	.391	.320	.412	.265	.279	.314	.268	.073
15	.147	.051	.098	.191	.177	.150	.256	.102	.172	.155	.173	.047
16	.141	.020	.106	.125	.244	.094	.249	.157	.170	.227	.183	.082
17	.100	.019	.092	.186	.200	.159	.178	.116	.116	.117	.094	.037
18	.045	0	.059	.114	.119	.109	.156	.068	.059	.077	.048	.025
19	.042	0	.018	.093	.083	.061	.085	.027	.030	.059	.025	.012
20	.021	0	.029	.040	.037	.036	.061	.046	.026	.031	.036	.017
21	.146	.013	.114	.226	.227	.245	.253	.143	.165	.053	.057	.062
22	.046	0	.053	.090	.074	.085	.082	.046	.053	.041	.027	.019
23	.045	0	.051	.072	.099	.086	.101	.038	.041	.057	.041	.017
24	.040	0	.048	.072	.092	.062	.097	.046	.026	0	.044	0
25	.060	0	.045	.063	.066	.089	.099	.044	.038	.057	.053	0
26	.030	0	.040	.041	.041	.039	.034	.018	.026	0	.041	.027
27	.154	.021	.158	.216	.272	.242	.210	.139	.122	.104	.046	.051
28	.045	.022	.072	.110	.065	.122	*	.037	.030	.064	.035	.016
29	.039	.014	.025	*	*	.071	*	.038	.034	.031	.035	.015
30	.019	0	.019	*	*	.064	*	.040	.031	.037	.086	.011
31	.080	0	.058	*	*	*	*	.069	.045	.056	0	.020
32	.046	0	.029	*	*	*	*	.037	.042	0	0	.021
Pristane	.116	.025	.104	.225	.232	.200	.227	.111	.117	.124	.105	.037
Phytane	.197	.032	.147	.368	.385	.299	.391	.154	.169	.237	.169	.046

* = No data; too many peaks on chromatograph.

All concentrations given in µg/g dry weight.

Statistical Analysis of n-Alkane Results
Aerobic Microcosms

	H				HS				O			
Alkane	1	24	49	100	1	24*	49	100	1	24	49	100*
9	76±26	0	0	0	81±15	77	62±7	0	49±15	0±0	0	0
10	825±28	140±26	47±7	0	912±21	853	679±5	33±88	630±12	0±0	0	0
11	1380±31	334±20	126±23	0	1532±24	1314	1053±7	79±86	1268±7	111±29	0	0
12	655±37	189±17	89±28	0	700±26	558	451±8	46±80	637±5	99±30	44±35	0
13	383±35	131±17	70±25	6±24	426±26	343	283±6	38±76	387±7	73±25	42±20	0
14	469±33	181±17	111±24	11±13	469±17	417	320±8	53±76	399±8	112±19	79±18	8
15	234±29	119±16	69±21	12±12	252±12	262	179±17	40±83	245±9	60±24	49±0	7
16	236±37	121±29	73±59	27±34	295±20	285	209±5	64±67	189±19	62±96	32±7	27
17	233±25	122±7	70±19	13±82	247±11	225	150±3	17±25	225±5	70±32	57±4	23
18	149±19	85±2	42±7	9±47	165±9	162	92±8	14±45	144±15	39±33	35±10	7
19	42±25	36±15	28±30	6±24	61±32	85	58±23	8±71	99±7	28±15	21±34	3
20	44±35	39±4	33±16	9±24	42±13	31	28±10	0	56±23	26±19	24±38	5
21	230±18	229±14	114±14	20±28	290±12	268	150±10	34±54	236±16	138±8	73±2	17
22	89±20	73±15	31±18	17±92	111±12	90	52±12	14±61	65±24	36±18	24±6	7
23	74±23	62±24	23±21	0	98±20	88	45±8	11±19	54±38	40±45	18±0	8
24	62±16	58±37	25±14	27±102	75±13	61	48±22	0	44±21	47±73	21±20	5
25	56±20	95±48	28±32	0	70±21	78	43±15	22±80	60±42	52±15	33±77	6
26	43±4	55±6	38±41	0	62±35	41	27±3	19±52	45±28	37±44	16±18	16
27	214±7	258±26	122±14	33±60	262±10	209	150±21	43±39	218±18	120±13	58±26	33
28	96±34	129±54	75±14	18±86	92±38	124	95±28	30±12	127±17	74±45	41±38	43
29	59±17	93±38	33±17	0	75±16	62	37±11	20±0	55±64	55±29	37±46	45
30	66±18	45±42	34±44	8±44	68±22	63	20±4	19±41	60±22	60±10	34±17	18
31	93±18	131±31	62±49	22±32	107±16	99	113±30	53±0	107±16	116±35	64±8	79
32	86±0	75±8	30±26	0	78±28	0	62±19	24±0	53±35	49±47	31±27	25

* Only One Data Point
Data reported as mean (W/g dry weight) ± coefficient of variation (%).

Statistical Analysis of n-Alkane Results
Anaerobic Microcosms

Alkane	A				AS			
	1	25	50	101	1	25	50	101
9	57±50	78±60	85±25	38±39	53±53	108±13	99±17	66±6
10	595±46	752±62	776±22	275±73	495±47	954±11	915±19	665±11
11	934±40	1152±59	1172±22	494±64	758±45	1437±11	1373±22	1044±19
12	379±37	480±59	487±23	234±58	314±42	616±10	489±1	429±21
13	207±33	266±56	260±17	158±52	177±34	328±12	260±0	246±18
14	228±37	300±55	291±16	198±48	204±27	363±10	319±25	291±11
15	120±29	155±53	172±31	128±51	123±28	173±12	177±44	164±8
16	120±45	187±68	141±55	160±35	124±20	154±51	192±26	205±15
17	119±28	165±53	128±21	74±43	96±6	182±11	137±26	106±15
18	74±13	109±51	74±7	63±27	52±19	114±4	94±57	63±33
19	47±17	39±23	65±35	26±41	30±57	79±21	47±69	42±57
20	35±72	77±4	41±43	24±44	25±23	38±5	44±40	34±10
21	122±9	175±38	160±24	60±21	130±17	233±4	187±31	55±5
22	41±14	63±38	56±32	380±81	50±10	83±10	60±32	34±29
23	33±34	53±36	50±50	0	48±9	86±16	60±59	44±23
24	31±34	46±38	39±42		44±13	75±20	56±65	44
25	27±39	64±58	48±55	0	53±20	73±19	60±56	55±5
26	28	32±42	25±37	22±22	35±20	40±3	26±31	41
27	140±34	112±73	140±39	81±56	156±2	243±12	157±30	75±55
28	76±26	73±37	47±6	108±61	59±32	99±30	34±15	50±41
29	44±47	23±3	35±67	6±183	32±22	*	36±8	33±9
30	21±24	*	0±	34±39	19±0	*	36±18	62±56
31	57±48	*	76±80	60±95	69±23	*	57±30	56
32	42±56	*	35±61	0	38±32	*	40±9	0

* No data; too many peaks in chromatograph.

Data reported as mean (µg/g dry weight) ± coefficient of variation (%).

BRANCHED AND AROMATIC HYDROCARBONS

A number of resolved peaks on FID-GC chromatograms were located between the more prominent n-alkane peaks. As such, they were not directly identified by KOVAT index. The KOVAT index system identifies alkanes by retention time and numbers n-alkanes such that KOVAT indices of 800, 900, and 1000 correspond to octane, nonane, and decane, etc. A compound that chromatographically elutes between two n-alkanes is assigned a KOVAT index between those two n-alkanes, based on retention time. For example, dichlorobenzene elutes between decane and undecane and is assigned a KOVAT index of 1009.

In order to identify these unknown peaks, all samples were analyzed by FID-GC and data-reduced by computer to yield KOVAT indices for all resolved peaks. Then the sample that showed the most unknown peaks (1-H-10) was analyzed by GC/MS, resulting in a data package that correlated KOVAT index with compound identification. The GC/MS KOVAT indices were then correlated with KOVAT indices from all the FID-GC-analyzed samples to give the data presented in the following tables.

Concentrations for raw data are given in µg/g dry weight while statistical data are given in ng/g dry weight. Statistical data are arranged with the means and coefficients of variation.

The final table in this appendix indicates the precision with which the GC/MS data system identified the unknown peaks of interest. Because larger branched alkanes can give ambiguous identifications, many of these compounds have been simply labelled "branched alkane" in the tables. Because pristane and phytane are known to have KOVAT indices of 1710 and 1815, respectively, they have been labelled as such.

H Systems

Compound	KOVAT	Sample #											
		1-H-2	1-H-6	1-H-10	24-H-1	24-H-14	24-H-15	49-H-4	49-H-7	49-H-12	100-H-5	100-H-9	100-H-11
Cyclohexen-1-ol	884	.201	.175	.205	.112	.117	.130	.156	.165	.257	.009		.007
2-Cyclohexen-1-one	926					.127							
Branched alkane	960		.041	.041									
Branched alkane	964	.051	.088	.090									
Branched alkane	970	.067	.117	.124	.028	.035	.054				.026		.066
Dichlorobenzene	1009	.089	.154	.143	.026	.053	.089						
Branched alkane	1022		.458	.165	.058	.065	.074	.033	.030				
Dichlorobenzene	1031	.213	.352	.311	.203	.218	.238	.153	.160	.223			.004
Branched Alkane	1034	.032	.058	.060									
Branched Alkane	1057	.122	.194	.181	.040	.047	.051	.019		.026			
Branched Alkane	1061	.084	.152	.147	.037	.040	.045						
Branched Alkane	1064	.161	.304	.304	.044	.052	.060	.021		.023			
Branched Alkane	1070	.137	.208	.210	.051	.058	.066	.023		.034			
Branched Alkane	1164	.080	.143	.145	.035	.032	.054			.023			
Branched Alkane	1214	.057	.100	.108	.039	.043	.053	.028		.031			
Branched Alkane	1365	.068	.115	.106	.052	.053	.069	.044	.029	.043			
Branched Alkane	1377	.114	.199	.215	.104	.106	.104	.097	.061	.109	.007	.047	
Branched Alkane	1462	.159	.241	.288	.137	.125	.168	.111	.101	.130	.021	.079	.012
Pristane	1708	.198	.295	.306	.204	.191	.237	.128	.103	.136	.033	.101	.015
Phytane	1815	.259	.411	.466	.264	.320	.340	.161	.153	.177	.036	.111	.019
3-Methyl-dibenzothiophene	1861	.039	.051										
Branched Alkane	1894	.088	.127	.153	.023	.086				.061			.006
Diisooctylphthalate	2557	3.716	2.277	2.751	2.466	2.199	2.541	.413	.393	.501	.235	1.747	.462

HS Systems

					ample #				
Compound	KOVAT	1-HS-6	1-HS-9	1-HS-15	24-HS-13	49-HS-1	49-HS-14	100-HS-11	100-HS-12
Cyclohexen-1-ol	884	.218	.212	.135	.174	.057	.174	.004	.018
Branched alkane	960	.040	.033	.065	.029		.019		
Branched alkane	964	.091			.082	.057	.063		
Branched alkane	970	.122	.102	.078	.101	.070	.090	.036	
Dichlorobenzene	1009	.079	.077	.039	.042	.041	.038		
Branched alkane	1022	.213	.170	.129	.163	.107	.139	.005	.015
Dichlorobenzene	1031	.090	.088	.061	.055	.060	.055		
Branched Alkane	1034	.073	.055	.041	.056	.040	.046		
Branched Alkane	1057	.205	.151	.137	.143	.109	.119		.011
Branched Alkane	1061	.170	.132	.105	.126	.082	.043		.008
Branched Alkane	1064	.336	.255	.198	.193	.160	.191		.010
Branched Alkane	1070	.241	.191	.158	.179	.111	.133		.015
Branched Alkane	1164	.166	.119	.115	.114	.065	.087		.013
Branched Alkane	1214	.122	.097	.084	.074	.057	.066		.011
Branched Alkane	1365	.121	.096	.083	.095	.055	.071		.015
Branched Alkane	1377	.182	.187	.160	.145	.099	.148	.006	.024
Branched Alkane	1462	.253	.240	.189	.252	.126	.167	.015	.043
Pristane	1708	.303	.282	.242	.296	.121	.186	.015	.034
Phytane	1815	.477	.357	.383	.410	.192	.240	.027	.099
3-Methyldibenzothiophene	1861		.026						
Branched Alkane	1894	.122	.157	.119	.129	.076	.073	.007	.017
Diisooctylphthalate	2557	4.119	3.308	3.999	.1222	.430	.547	.362	

O Systems

		Sample #										
Compound	KOVAT	1-0-1	1-0-12	1-0-14	24-0-3	24-0-5	24-0-15	49-0-2	49-0-7	49-0-13	100-0-10	100-0-11
Cyclohexen-1-ol	884	.252	.229	.219	.173	.115	.137	.191	.149	.122	.006	
2-Cyclohexen-1-one	926	.027				.124	.149	.160	.147	.108		
Branched alkane	960	.033	.026	.031								
Branched alkane	964	.072	.064	.074							.030	
Branched alkane	970	.102	.095	.102								
Dichlorobenzene	1009	.154	.145	.126								
Branched alkane	1022	.179	.083	.105		.036		.029	.053	.027		
Dichlorobenzene	1031	.359	.343	.290	.022							
Branched Alkane	1034	.058	.052	.067								
Branched Alkane	1057	.166	.146	.156								
Branched Alkane	1061	.144	.122	.135								
Branched Alkane	1064	.270	.235	.261								
Branched Alkane	1070	.191	.176	.189	.021							
Branched Alkane	1164	.126	.117	.124	.024							
Branched Alkane	1214	.098	.090	.102	.032		.022					
Branched Alkane	1365	.101	.100	.091	.045	.037	.041	.038	.028			
Branched Alkane	1377	.214	.176	.188	.123	.083	.092	.076	.062		.005	
Branched Alkane	1462	.245	.220	.215	.142	.111	.124	.095	.072	.021	.012	.047
Pristane	1708	.292	.279	.277	.187	.119	.127	.105	.112	.036	.009	.076
Phytane	1815	.364	.335	.384	.206	.214	.179	.192	.139	.052	.030	.078
3-Mehtyl dibenzothiophene	1861			.026								
Branched Alkane	1894	.034	.037	.045	.027	.021	.021	.019	.031			
Diisooctylphthalate	2557	1.974	3.670	2.674	1.203	1.479	3.157	.519	.372	.181	.142	.305

A Systems

		Sample #											
Compound	KOVAT	1-A-1	1-A-6	1-A-15	25-A-2	25-A-7	25-A-8	50-A-4	50-A-11	50-A-12	101-A-5	101-A-9	101-H-13
Cyclohexen-1-ol	884	.093	.132	.091	.157	.155	.046	.153	.170	.134			.011
2-Cyclohexen-1-one	926		.024					.022	.027	.026			
Branched alkane	960	.019	.045	.014	.107	.161		.027	.048	.033	.036		
Branched alkane	964	.043	.081	.036	.073	.107		.054	.085	.069			
Branched alkane	970	.058	.109	.048	.096	.145	.030	.073	.113	.092	.034	.057	.146
Dichlorobenzene	1009	.064	.124	.039	.095	.151	.031	.073	.109	.094	.043	.054	
Branched alkane	1022	.045	.088	.051	.089	.147	.045	.085	.110	.105	.052	.080	.013
Dichlorobenzene	1031	.156	.307	.081	.261	.400	.083	.188	.303	.224	.137	.153	.014
Branched Alkane	1034	.033	.057	.026	.046	.075		.038	.054	.048			
Branched Alkane	1057	.103	.184	.080	.182	.254	.060	.113	.179	.155	.059	.093	.016
Branched Alkane	1061	.073	.131	.057	.114	.166	.035	.080	.123	.112	.044	.067	.010
Branched Alkane	1064	.147	.267	.113	.242	.344	.070	.167	.274	.234	.096	.149	.019
Branched Alkane	1070	.102	.178	.084	.163	.234	.055	.110	.179	.154	.063	.099	.019
Branched Alkane	1164	.076	.111	.050	.103	.151	.036	.066	.117	.102	.043	.070	.017
Branched Alkane	1214	.052	.071	.039	.073	.097	.026	.046	.080	.065	.039	.048	.014
Branched Alkane	1365	.047	.069	.041	.073	.112	.029	.046	.065	.054	.046	.058	.016
Branched Alkane	1377	.099	.146	.071	.154	.186	.047	.097	.134	.116	.084	.118	.030
Branched Alkane	1462	.118	.139	.080	.176	.208	.069	.117	.149	.123	.100	.153	.045
Pristane	1708	.131	.202	.113	.231	.268	.083	.105	.173	.140	.065	.118	.043
Phytane	1815	.171	.259	.156	.349	.417	.111	.115	.298	.262	.068	.214	.104
Branched Alkane	1894	.021	.030	.013	.083	.159	.034	.020	.046	.03[illegible]			
Diisooctylphthalate	2557	1.735	1.731	2.233	.726	3.612	.515	.285	.426	.959	.099		.083

AS Systems

		Sample #											
Compound	KOVAT	1-AS-7	1-AS-13	1-AS-15	25-AS-1	25-AS-4	25-AS-11	50-AS-2	50-AS-8	50-AS-14	101-AS-6	101-AS-9	101-AS-12
Cyclohexen-1-ol	884	.151		.125	.190	.198	.156	.184	.180	.175			.013
2-Cyclohexen-1-one	926				.029	.033	.028	.035	.027				
Branched alkane	960	.027			.036	.045	.030	.049	.033	.035	.030	.073	
Branched alkane	964	.061	.022	.028					.073		.040	.044	
Branched alkane	970	.081	.029	.035	.115	.133	.107	.134	.102	.096	.083	.080	
Dichlorobenzene	1009	.044			.060	.058	.054	.061	.046	.079	.044	.036	
Branched alkane	1022	.074	.032		.097	.123	.087	.183	.091	.121	.121	.111	.014
Dichlorobenzene	1031	.075	.029	.057	.084	.074	.096	.089	.076	.095	.090	.059	
Branched Alkane	1034	.046		.019	.063	.075	.057	.074	.057	.052	.035	.034	
Branched Alkane	1057	.117	.049	.062	.184	.191	.154	.199	.144	.133	.121	.099	.013
Branched Alkane	1061	.091	.033	.042	.131	.149	.122	.151	.112	.110	.092	.078	.008
Branched Alkane	1064	.183	.062	.083	.260	.293	.237	.304	.179	.219	.205	.165	.015
Branched Alkane	1070	.124	.048	.066	.192	.215	.170	.217	.162	.147	.142	.113	.017
Branched Alkane	1164	.076	.030	.044	.122	.136	.107	.150	.096	.098	.124	.067	.015
Branched Alkane	1214	.061	.021	.034	.083	.090	.070	.099	.065	.066	.063	.048	.012
Branched Alkane	1365	.050		.037	.077	.080	.065	.080	.056	.054	.067	.064	.016
Branched Alkane	1377	.101	.038	.069	.160	.158	.134	.155	.113	.116	.133	.103	.022
Branched Alkane	1462	.127	.047	.085	.171	.187	.147	.247	.122	.114	.168	.135	.041
Pristane	1708	.116	.025	.104	.225	.232	.200	.227	.111	.117	.124	.105	.037
Phytane	1815	.197	.032	.147	.368	.385	.299	.391	.154	.149	.237	.169	.046
Branched Alkane	1894			.045	.039			.043	.063	.024			
Diisooctylphthalate	2557	1.720	.374	1.673	1.066	1.252	2.108	1.195	.427	.720	1.300		.612

Statistical Analysis of GC/MS:GC-FD Correlations
Aerobic Systems

Microcosm Type		H	H	H	H	HS	HS	HS	HS	0	0	0	0
Days of Incubation	KOVAT	1	24	49	100	1	24*	49	100	1	24	49	100
Cyclohexen-1-ol	884	194±8	120±8	193±29	8±18	188±25	174	116±71	11±90	233±7	142±21	154±23	
2-Cyclohexen-1-one	926										91±88	138±20	
Branched alkane	960	41±0				46±37	29	19*	18*	30±12			
Branched alkane	964	76±29					82	60±7		70±8			
Branched alkane	970	103±30	39±34		16±88	101±22	101	80±18	10±71	100±4			
Dichlorobenzene	1009	129±27	56±56			65±35	42	40±5		142±10			
Branched alkane	1022	312±66	66±12	32±7		171±25	163	123±18		109±62		36±40	
Dichlorobenzene	1031	292±24	220±8	179±22		80±20	55	58±6		331±11			
Branched Alkane	1034	50±31				56±29	56	43±10		59±13			
Branched Alkane	1057	166±23	46±12	23±22		164±22	143	114±6	*	156±6			
Branched Alkane	1061	128±30	41±10			136±24	126	88±9	*	134±8			
Branched Alkane	1064	256±32	52±15	22±6		263±26	193	176±12	*	255±7			
Branched Alkane	1070	185±22	58±13	29±27		197±21	179	122±13	*	185±4			
Branched Alkane	1164	123±30	40±30			133±21	114	76±20	*	122±4			
Branched Alkane	1214	88±31	45±13	30±7		101±19	74	62±10	*	97±6	27±26		
Branched Alkane	1365	96±26	58±16	39±22		100±19	95	63±18	*	97±6	41±10	33±21	
Branched Alkane	1377	176±31	105±1	89±28	7	176±8	145	124±28	15±85	193±10	99±21	69±14	
Branched Alkane	1462	229±29	143±16	114±13	17±37	227±15	252	147±20	29±68	227±7	126±12	84±19	30±82
Pristane	1710	266±22	211±11	122±14	24±53	276±11	296	154±30	25±54	283±3	144±26	109±5	43±110
Phytane	1815	379±28	308±13	164±7	28±43	406±16	410	216±16	63±81	361±7	200±9	166±23	54±63
3-Methyl dibenzothiophene	1861	45±19											
Branched Alkane	1894	123±27	55±81			133±16	129	75±3	12±59	39±15	23±15	25±34	
Diisooctylphthalate	2557	2915±25	2402±7	436±13	349±46	3809±11	1222	489±17	362*	2773±31	1946±54	446±23	224±51

* = Only one data point.

Statistical Analysis of GC/MS:GC-FID Correlations
Anaerobic Systems

Microcosm Type		A	A	A	A	AS	AS	AS	AS
Days of Incubation		1	25	50	101	1	25	50	101
Compound	KOVAT								
Cyclohexen-1-ol	884	105±22	156±1	152±12		138±13	181±12	180±3	
2-Cyclohexen-1-one	926		25±11				30±9	31±18	
Branched alkane	960	26±64	134±28	36±30			37±20	39±22	52±58
Branched alkane	964	53±46	90±27	69±22		45±52			42±7
Branched alkane	970	72±45	121±29	93±22	46±35	58±56	118±11	111±18	82±3
Dichlorobenzene	1009	76±57	123±32	92±20	49±16		57±5	62±27	40±14
Branched alkane	1022	61±38	118±35	100±13	66±30		102±18	132±36	116±6
Dichlorobenzene	1031	181±64	331±30	238±25	145±8	66±19	85±13	87±11	75±29
Branched Alkane	1034	39±42	61±34	47±17		33±58	65±14	61±19	35±2
Branched Alkane	1057	122±45	219±24	149±22	76±32	90±43	176±11	159±22	110±14
Branched Alkane	1061	87±45	140±26	105±21	56±29	67±52	134±10	124±19	85±12
Branched Alkane	1064	176±46	293±25	225±24	123±30	133±53	263±11	234±27	185±15
Branched Alkane	1070	121±41	199±25	148±24	81±31	95±43	192±12	175±21	128±16
Branched Alkane	1164	79±39	127±27	95±28	57±33	60±38	122±12	115±27	96±42
Branched Alkane	1214	54±30	85±20	64±27	44±14	48±40	81±13	77±25	56±19
Branched Alkane	1365	52±28	93±30	55±17	52±16	44±21	74±11	63±23	66±3
Branched Alkane	1377	105±36	170±13	116±16	101±24	85±27	151±10	128±18	118±18
Branched Alkane	1462	112±27	192±12	130±13	127±30	106±28	168±9	161±46	152±15
Pristane	1710	149±32	250±10	139±24	92±41	110±8	219±8	152±43	115±12
Phytane	1815	195±29	383±13	225±43	129±59	172±21	351±13	231±60	203±24
Branched Alkane	1894	21±40	121±44	33±39				43±45	
Diisooctylphthalate	2557	1900±15	2169±94	557±64		1697±2	1475±38	781±50	

GC/MS IDENTIFICATION AND PRECISION OF UNKNOWN FID-GC PEAKS

Scan#	KOVAT	Purity	Fit	GC/MS Identification
271	816	944	989	Tetrachloroethene
381	857	309	885	Ethenyl oxirane (ethylene oxide)
456	884	778	946	1-cyclohexen-1-ol
567	926	935	984	2-cyclohexene-1-one
661	960	832	942	2,2,3,3-Tetramethylpentane
670	964	526	946	4,5-Dimethyl-1-hexene
688	970	732	937	3-Methylnonane
793	1009	869	996	1,3-Dichlorobenzene
827	1022	922	960	2,5,5,-Trimethylheptane
852	1031	823	935	1,2-Dichlorobenzene
861	1034	796	948	2,2-Dimethylbutane
923	1057	760	941	3-Ethyl-2,3-dimethylpentane
932	1061	941	976	4-Methyldecane
942	1064	907	976	2-Methyldecane
958	1070	940	977	3-Methyldecane
1207	1164	895	961	3-Methyldecane
1336	1214	922	979	2,5,9-Trimethyldecane
1704	1365	652	875	2,5-Dimethylhexane
1732	1377	800	933	2,6,11-Trimethyldodecane
1925	1462	895	974	3-Methyl-5-propylnonane
2438	1708	875	953	5-Propyltridecane
2633	1815	604	973	4-Methyl-2-propyl-1-pentanol
2727	1861	719	950	3-Methyldibenzothiophene
2787	1894	686	973	3,8-Dimethylundecane
3822	2557	298	930	5-Ethyl-2-Methylheptane

COMPUTER-REDUCED DATA, STATISTICAL EVALUATIONS, AND FIGURES FROM FID-GC ANALYSIS OF MICROCOSM EXTRACTS

The following tables indicate hydrocarbon totals, sums, and ratios as derived from the computerized Gas Chromatographic Data Reduction program. All nonratio values are given in μg/g dry weight.

GC-FID REDUCED DATA
Aerobic Microcosms

Sample #	Total Resolved Hydrocarbons	Total Unresolved Hydrocarbons	Ratio Unresolved:Resolved Hydrocarbons	Sum n-Alkanes	Ratio Odd:Even Alkanes	Ratio Pristane:C17	Ratio Phytane:C18	Ratio Pristane: Phytane	Ratio n-Alkanes: Branched Alkanes
1-H-2-S-BNA	17.2	160	9.30	2.71	0.837	1.20	2.[illegible]0	0.765	0.187
1-H-6-S-BNA	21.1	204	9.67	3.84	0.803	1.14	[illegible].51	0.717	0.223
1-H-10-S-BNA	22.6	252	11.2	4.05	0.890	1.11	2.80	0.656	0.218
24-H-1-S-BNA	11.4	146	12.8	1.71	1.38	1.78	3.17	0.771	0.176
24-H-14-S-BNA	14.0	183	13.1	2.41	1.17	1.58	3.73	0.598	0.208
24-H-15-S-BNA	16.6	200	12.0	2.68	1.35	1.81	3.94	0.699	0.193
49-H-4-S-BNA	6.67	97.0	14.5	1.22	1.01	1.72	3.55	0.795	0.224
49-H-7-S-BNA	5.43	83.3	15.3	0.929	1.41	1.88	3.94	0.676	0.206
49-H-12-S-BNA	8.64	127	14.7	1.44	1.04	1.71	4.30	0.770	0.200
100-H-5-S-BNA	1.38	26.43	19.2	0.408	1.023	1.66	2.97	0.907	0.337
100-H-9-S-BNA	1.14	162.52	142	0.386	0.386	1.76	0.987	0.913	0.154
100-H-11-S-BNA	0.68	16.80	24.7	0.161	0.904	2.99	3.10	0.769	0.146
1-HS-6-S-BNA	25.0	258	10.3	4.28	0.785	1.15	2.90	0.635	0.207
1-HS-9-S-BNA	22.9	245	10.7	4.16	0.923	1.08	2.00	0.789	0.222
1-HS-15-S-BNA	20.1	198	9.85	3.55	0.955	1.17	2.56	0.658	0.215
24-HS-2-S-BNA	LOST								
24-HS-13-S-BNA	18.3	208	11.4	3.55	0.937	1.31	2.52	0.722	0.241
49-HS-1-S-BNA	10.7	103	9.63	2.13	0.888	1.03	3.01	0.634	0.248
49-HS-14-S-BNA	14.9	135	9.06	2.82	0.882	1.21	2.46	0.775	0.233
100-HS-11-S-BNA	1.24	17.52	14.1	0.419	1.113	1.05	2.99	0.560	0.348
100-HS-12-S-BNA	3.06	59.76	19.5	0.739	0.898	1.71	5.53	0.339	0.271
1-0-1-S-BNA	18.5	125	6.76	3.32	0.885	1.27	2.55	0.803	0.219
1-0-12-S-BNA	20.4	163	8.00	3.51	0.949	1.31	2.73	0.832	0.208
1-0-14-S-BNA	19.8	166	8.38	3.67	0.954	1.19	2.30	0.722	0.227
24-0-3-S-BNA	9.83	193	19.6	1.52	1.05	2.02	4.25	0.907	0.182
24-0-5-S-BNA	7.50	140	18.7	1.14	1.39	2.51	8.78	0.556	0.179
24-0-15-S-BNA	12.0	178	14.8	1.52	1.15	1.83	4.17	0.711	0.145
49-0-2-S-BNA	5.84	111	19.0	0.861	1.23	1.90	5.93	0.545	0.173
49-0-7-S-BNA	3.60	76.9	21.4	0.641	1.25	1.88	3.26	0.794	0.216
49-0-13-S-BNA	1.12	25.0	22.3	0.0578	2.64	0.369	0.474	0.779	0.0543
49-0-7-S-BNA	4.58	88.8	19.4	0.791	1.12	1.93	3.71	0.808	0.209
49-0-13-S-BNA	1.28	26.4	20.6	0.113	4.70			0.701	0.0966
100-0-10-S-BNA	0.99	24.25	24.5	0.334	1.30	1.13	4.40	0.292	0.421
100-0-11-S-BNA	1.08	166.13	154	0.214	2.54	1.98	0.696	0.969	0.182

GC-FID REDUCED DATA
Anaerobic Microcosms

	Total Resolved Hydrocarbons	Total Unresolved Hydrocarbons	Ratio Unresolved:Resolved Hydrocarbons	Sum n-Alkanes	Ratio Odd:Even Alkanes	Ratio Pristane:C17	Ratio Phytane:C18	Ratio Pristane: Phytane	Ratio n-Alkanes: Branched Alkanes
1-A-1-S-BNA	10.6	84.2	7.94	1.81	0.943	1.17	2.39	0.768	0.206
1-A-6-S-BNA	17.2	116	6.74	2.70	0.847	1.31	3.10	0.781	0.187
1-A-15-S-BNA	9.63	68.4	7.10	1.41	0.985	1.28	2.36	0.723	0.172
25-A-2-S-BNA	16.4	148	9.02	3.01	0.827	1.21	2.53	0.662	0.224
25-A-7-S-BNA	21.5	191	8.88	3.38	0.825	1.13	2.92	0.642	0.187
25-A-8-S-BNA	5.34	59.1	10.9	1.06	1.11	1.21	2.48	0.746	0.249
50-A-4-S-BNA	9.59	73.1	7.62	1.76	0.763	0.989	1.67	0.910	0.225
50-A-11-S-BNA	15.6	155	9.94	2.71	0.830	1.10	3.76	0.581	0.210
50-A-12-S-BNA	15.3	130	8.50	2.51	1.08	1.17	3.50	0.536	0.196
101-A-5-S-BNA	5.47	201.12	36.8	1.93	0.332	0.924	1.05	0.952	0.523
101-A-9-S-BNA	9.94	271.63	27.3	3.08	0.434	1.09	2.70	0.552	0.450
101-A-13-S-BNA	3.70	68.01	18.4	0.917	0.836	0.972	2.35	0.411	0.322
1-AS-7-S-BNA	12.1	114	9.42	2.11	0.954	1.16	4.33	0.590	0.211
1-AS-13-S-BNA	5.70	60.2	10.6	0.930	1.06	1.40	2.62	0.679	0.195
1-AS-15-S-BNA	8.21	77.8	9.48	1.56	0.900	1.37	2.85	0.629	0.234
25-AS-1-S-BNA	16.5	153	9.27	1.60	0.867	1.21	3.24	0.612	0.221
25-AS-4-S-BNA	18.1	182	10.1	3.21	0.856	1.16	3.23	0.603	0.217
25-AS-11-S-BNA	17.5	144	8.23	2.87	0.938	1.26	2.75	0.669	0.196
50-AS-2-S-BNA	17.8	185	10.4	1.82	0.855	1.28	2.51	0.582	0.234
50-AS-8-S-BNA	12.7	102	8.03	2.23	0.781	0.958	2.27	0.719	0.212
50-AS-14-S-BNA	12.9	115	8.91	2.25	0.833	1.00	2.52	0.782	0.211
101-AS-6-S-BNA	10.58	134.44	12.7	2.26	0.751	1.06	3.08	0.526	0.235
101-AS-9-S-BNA	8.00	111.98	14.0	1.88	0.652	1.12	3.52	0.621	0.307
101-AS-12-S-BNA	2.85	51.97	18.2	0.691	0.860	1.00	1.87	0.803	0.246

Statistical Analysis of GC-FID Reduced Data

Day - Treatment	Total Resolved Hydrocarbons	Total Unresolved Hydrocarbons	Ratio Unresolved:Resolved Hydrocarbons	Sum n-Alkanes	Ratio Odd:Even Alkanes	Ratio Pristane:C17	Ratio Phytane:C18	Ratio Pristane: Phytane	Ratio n-Alkanes: Branched Alkanes
1-H	20.3±14	205±22	10.1±10	3.53±20	0.843±5	1.15±43	2.50±12	.713±8	.209±10
24-H	14.0±19	176±16	12.6±5	2.27±22	1.30±8	1.72±8	3.61±11	.689±13	.192±8
49-H	6.91±23	102±22	14.8±3	1.20±22	1.15±19	1.77±5	3.93±10	.747±8	.210±6
100-H	1.07±33	69±119	64±68	.318±43	.771±44	2.14±35	3.04±3	.838±12	.212±51
1-HS	22.7±11	234±14	10.3±4	4.00±10	.888±10	1.13±4	2.49±18	.694±12	.215±4
24-HS*	18.3	208	11.4	3.55	.937	1.31	2.52	.722	.241
49-HS	12.8±23	119±19	9.35±4	2.48±20	.885±0.48	1.12±11	2.74±14	.705±14	.241±4
100-HS	2.15±60	39±77	18±4	.58±39	1.01±15	1.38±34	4.26±42	.450±35	.310±18
1-O	19.6±5	151±15	7.71±10	3.50±5	.929±4	1.26±5	2.53±9	.786±7	.218±5
24-O	9.78±23	170±16	17.7±15	1.39±16	1.20±14	2.12±17	5.73±45	.725±23	.169±12
49-O	3.52±67	71.0±61	20.9±8	.520±80	1.71±47	1.38±64	3.22±85	.706±20	.148±57
100-O	1.04±6	95±105	91±92	.274±31	1.92±24	1.56±39	4.40±0	.292±0	.302±56
1-A	12.5±33	89.5±27	7.26±9	1.97±34	.925±8	1.25±6	2.62±16	.757±4	.188±9
25-A	14.4±57	132±51	9.60±12	2.48±50	.921±18	1.18±4	2.64±9	.683±8	.220±14
50-A	13.5±25	119±35	8.69±13	2.33±21	.891±19	1.09±8	2.98±38	.676±25	.210±7
101-A	6.37±50	180±57	28±9	1.98±55	.534±50	.995±9	2.03±43	.638±44	.432±24
1-AS	8.67±37	84±33	9.83±7	1.53±39	.971±8	1.31±10	3.27±28	.633±7	.213±9
25-AS	17.4±5	160±12	9.20±10	2.56±33	.887±5	1.21±4	3.07±9	.628±6	.211±6
50-AS	14.5±20	1340±33	9.11±13	2.10±12	.823±5	1.08±16	2.43±6	.694±15	.219±6
101-AS	9.29±20	123±13	15±3	2.07±13	.754±14	1.06±6	2.82±30	.650±22	.263±15

Statistical data given as mean ± coefficient of variation (%). Means for non-ratio results are in μg/g dry weight; ratio results are unitless.

* = only 1 data point

APPENDIX E

QUALITY ASSURANCE/QUALITY CONTROL PLAN FOR LABORATORY BIODEGRADATION STUDY

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SECTION I

QUALITY ASSURANCE OBJECTIVES

The QA objectives for this task are to maintain an adequate and feasible level of Quality Control, given the project's constraints.

In general, the objectives are:

- Data generated should be accurate in terms of their agreement with reference or true values.
- Data should be precise and should agree among individual measurements made under similar conditions.
- Data should be comparable to prior relevant data for evaluation purposes.
- Data should be reproducible and obtainable under similar conditions, whether generated by the project laboratory or another laboratory.

The quality assurance plan has been prepared with the intention of covering the major analytical parameters and situations that are anticipated in this work assignment. These procedures are followed by all personnel involved in the project.

SECTION II

ANALYTICAL PROCEDURES FOR BIORECLAMATION

The analysis of microcosm sediment and water for the Bioreclamation Program involves solvent extraction, liquid chromatography, fractionation into aliphatic, aromatic and polar fractions and instrumental analysis by a combination of FID-GC, ECD-GC and GC/MS. Extraction procedures for the two types of samples which will be generated by this study are listed in the following section.

A. EXTRACTION OF ORGANICS IN MICROCOSMS

1. Analytical Method

JRB's Applied Environmental Sciences Laboratory utilizes the protocols employed for priority pollutant sample preparation involving aqueous media set forth by EPA method 625 (Federal REgister, 1979). This methodology is followed as written, including: reagents, equipment, procedures and QA precautions.

Microcosm soil samples are prepared for priority pollutant analysis utilizing a sonication extraction procedure. Figure E-1 presents a flow chart of the analytical procedure. A brief summary of this protocol follows:

- Microcosms selected for sacrifice are shaken to evenly mix sediment and water fractions. Approximately 40 ml of this mixture is removed for volatile organic analysis (VOA), and 1 ml is removed for plate counts to verify viability of microcosms.
- The remaining sample is centrifuged at 2500 rpm for 10 minutes in the microcosm bottle. Approximately 15 ml of the water is removed for temperature, pH, Eh, dissolved oxygen, and peroxide concentration determinations.
- The remaining water undergoes continuous liquid/liquid extraction following Federal Register Method 625.

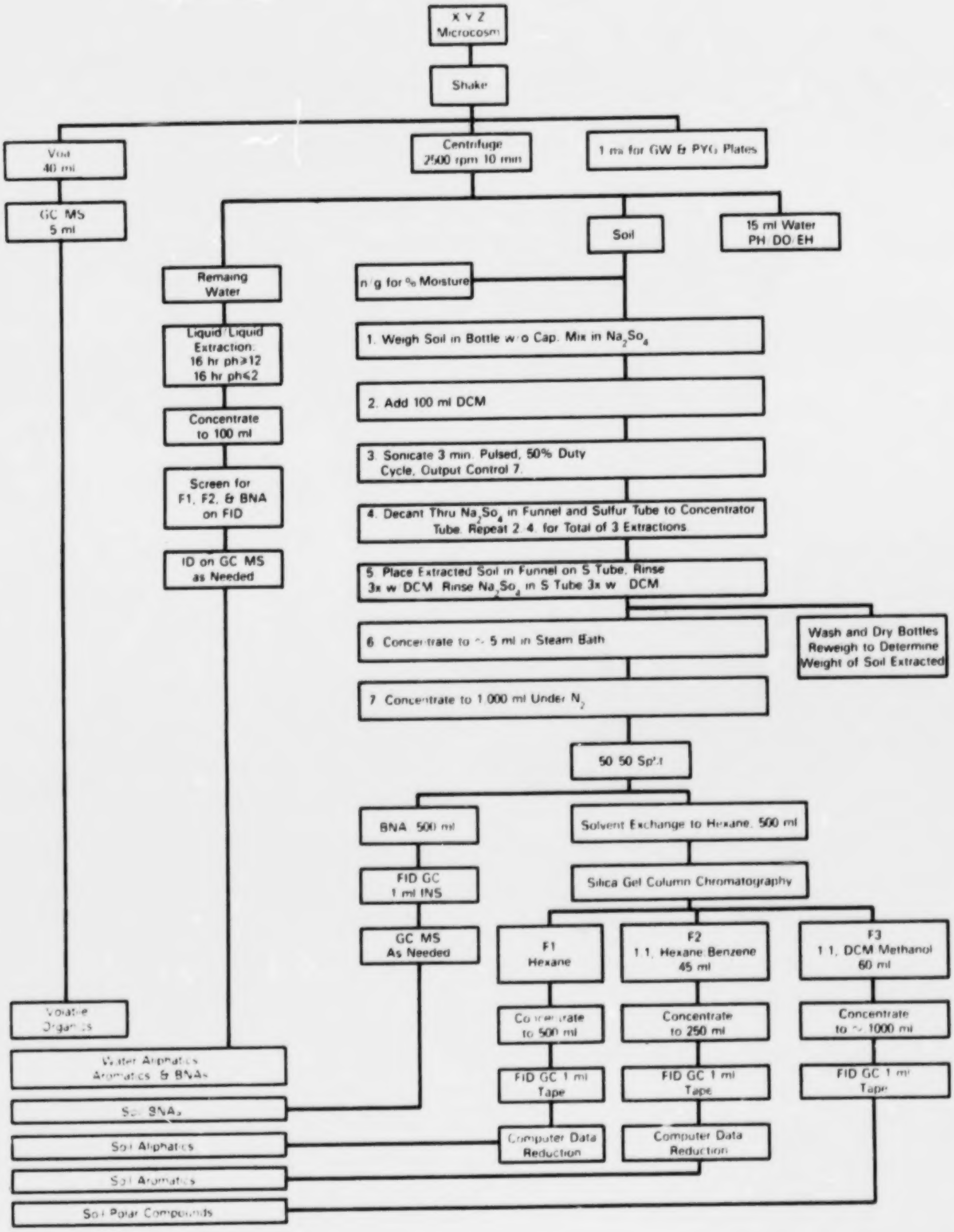
X Y Z Microcosm
Shake
Vial 40 ml
Centrifuge 2500 rpm 10 min
1 ml for GW & PYG Plates
GC MS 5 ml
Soil
15 ml Water PH DO EH
Remaing Water
n/g for % Moisture
Liquid/Liquid Extraction: 16 hr ph≥12 16 hr ph≤2
1. Weigh Soil in Bottle w/o Cap. Mix in Na2So4
2. Add 100 ml DCM
Concentrate to 100 ml
3. Sonicate 3 min. Pulsed, 50% Duty Cycle, Output Control 7.
Screen for F1, F2, & BNA on FID
4. Decant Thru Na2So4 in Funnel and Sulfur Tube to Concentrator Tube. Repeat 2-4. for Total of 3 Extractions.
ID on GC MS as Needed
5. Place Extracted Soil in Funnel on S Tube, Rinse 3x w DCM. Rinse Na2So4 in S Tube 3x w DCM
6. Concentrate to ~ 5 ml in Steam Bath
Wash and Dry Bottles Reweigh to Determine Weight of Soil Extracted
7. Concentrate to 1.000 ml Under N2
50 50 Split
BNA 500 ml
Solvent Exchange to Hexane, 500 ml
FID GC 1 ml INS
Silica Gel Column Chromatography
GC MS As Needed
F1 Hexane
F2 1:1, Hexane Benzene 45 ml
F3 1:1, DCM Methanol 60 ml
Volatile Organics
Concentrate to 500 ml
Concentrate to 250 ml
Concentrate to ~ 1000 ml
Water Aliphatics Aromatics, & BNAs
FID GC 1 ml Tape
FID GC 1 ml Tape
FID GC 1 ml Tape
Soil BNAs
Soil Aliphatics
Computer Data Reduction
Computer Data Reduction
Soil Aromatics
Soil Polar Compounds

Figure E-1. Bioreclamation Flow Diagram of Analyses

- After removing approximately 1 gm soil from selected microcosms for dry weight analysis, and weighing the remaining soil in the bottle, 100 ml methylene chloride (DCM) are added and the sample is extracted utilizing pulsed sonication.

- The DCM extract is then decanted through sodium sulfate in a funnel and sulfur tube into a K-D flask fitted wtih a concentrator tube. A total of three DCM addition, extraction, and desiccation steps are performed on each sample with all dried extracts combined in the K-D flask/concentrator tube.

- The soil is deposited on the above funnel and rinsed three times with DCM followed by a triple DCM rinse of the sodium sulfate in the sulfur tube. The emptied bottles are then dried and weighed to determine the wet weight of the extracted soil.

- The DCM extract is then concentrated to approximately 5 ml in a steam bath and finally concentrated to 1.000 ml under a nitrogen stream.

- The 1 ml extract is divided into two 500 μl splits. From selected Split A samples, 1 μl is analyzed by GC/MS for compound identification.

- Split B is solvent exchanged to hexane and fractionated by silica gel column chromatography into aliphatic (F_1), aromatic (F_2), and polar (F_3) fractions.

- The Split B fractions are further concentrated to appropriate volumes (250-1000 μl) and analyzed by FID-GC.

- During FID-GC analysis, all data are recorded on cassette tape. These data are subsequently loaded on to the DEC-10 computer and reduced via the SAIC GC Data Reduction program to determine total resolved and unresolved hydrocarbons, sum of n-alkanes, ratios of various compounds or compound types, and concentrations of specific as-yet unknown peaks.

- These unknown peaks are correlated with GC/MS data obtained from selected Split A samples. Positive compound verification identification is assigned by utilizing retention times, KOVAT indices and other comparative techniques.

SECTION III

CHROMATOGRAPHIC DATA ANALYSIS

Chromatography is an analytical process which is capable of separating samples into components prior to their being measured by some detection device. This enables qualitative identification by retention time (position in the separation sequence) as well as quantitative measurement by detector response when compared to known amounts of standards. By far the most common chromatographic analysis employed for measuring complex organic materials is gas chromatography which can be coupled to a variety of detectors (flame ionization, electron capture, mass spectrometry). This section describes the analytical principle of each detection device as it pertains to generating data for the Bioreclamation task.

Flame ionization detection (FID) operates on the principal that the electrical conductivity of a gas is directly proportional to the concentration of charged particles within the gas. This detector is selective for hydrocarbon compounds with oxidizable carbon atoms (C-H bonds), which when oxidized in the hydrogen-air flame produces a plasma of highly unstable radicals, positive and negative ions. These charged particles are collected and cause current flow in what was previously an electrostatic field. The current produced by the ionized molecule is changed to a voltage output by an electrometer, and this output is quantitatively altered to an integrated chromatographic peak. The minimum detection limit is 10^{-11} g with a linear range of 10^7 for concentration.

Electron capture detection (ECD) is based on electron absorption by compounds having an affinity (electronegativity) for free electrons, and this detector is selective for halogen-containing species. A radioactive source (^{63}Ni) expels electrons toward an anode, which collide with the carrier gas (argon/methane) and cause ejection of low energy secondary electrons. The anode collects these secondary electrons,thus,creating a steady-state current, which is altered (decreased) when electronegative compounds enter the detector. The detector senses the current drop and responds by countering the drop, thus, creating an output signal for individual components entering the detector. The minimum detection limit is 10^{-14} g with a linear range of 10^3 for concentration.

For each of these detector types, the response output is converted to an integrated chromatographic peak for a given compound within the sample matrix. The integrated peak area is converted to concentartion data by use of an external standard which contains components of the same nature as those of interest in the unknown sample matrix (i.e., petroleum hydrocarbons, chlorinated hydrocarbons, etc.). A gas chromatograph can be calibrated by injecting an external standard for subsequent GC microprocessor calculation of response factors (μg/peak area) for the individual standard components. These response factors are applied to the integrated peak areas for unknown sample components based upon relative retention times (by interpolation when an unknown elutes at a retention time in between two standard components). The total concentration for a given component in the unknown is then calculated. Internal standards are also utilized to calculate recovery data for adjustment of GC concentration data to account for component losses during sample workup and subsequent analysis.

A microprocessor-based gas chromatograph, interfaced to an automated data recorder (tape or disc), enables permanent storage of calibration data, retention times and peak areas. Discs (or tapes) can then be introduced to a main computer for further data analysis. Sophisticated data reduction programs exist for a number of sample matrix types, including petroleum hydrocarbons and organohalogens, which generate additional information (resolved/unresolved component ratios, etc.) which is useful in characterizing the raw chromatographic data.

SECTION IV

GC CALIBRATION PROCEDURES

The following describes methods of performing calibration of the analytical instrumentation and the frequency which each calibration type will be performed. These procedures will be routinely followed on all programs requiring quantitative analysis of organic constitutents.

A. GENERAL PROCEDURES

Step-by-step written calibration procedures are kept with each instrument. All calibration procedures are based on reference standards traceable to the NBS and/or EPA. Manufacturer's recommendations are followed when periodic calibration of an instrument is required. To insure calibration on instruments with daily variances, three calibration samples at the low, middle, and high ends of the working range are analyzed before any samples are run, and at the end of the instrument working day.

B. GAS CHROMATOGRAPHY

1. Selective Detectors

Gas Chromatographs (fused silica capillary column) are recalibrated using appropriate reference standards after every ten injections. Retention times and response factors for each standard run are logged into a bound notebook kept with each instrument. If response factors vary more than two standard deviations and/or retention times vary ± 15 seconds remedial action is instituted. In addition to retention time and response factor calibration of the instrument, linearity plots are run and recorded routinely to ensure that analyses are being completed within the linear range of the instrument.

In addition to the calibration and quantitation procedures described above, daily checks on instrument parameters are also performed to insure that gas chromatographs and supporting hardware (i.e., septums, pneumatic systems, tape and disc drives, etc.) function properly. Hand calculations (checks) of software programs used in data reduction systems are performed periodically on selected samples.

2. FID-Gas Chromatography, Hydrocarbon Calibration

Hydrocarbon analyses are performed on Hewlett-Packard 5840 gas chromatographs equipped with capillary inlet systems and fused silica capillary columns. Gas chromatographs are recalibrated daily or after ten injections during 24 hr/day operations, using a series of even and odd n-alkanes, from nC-8 through nC-32, and aromatic hydrocarbons as appropriate. As with selective detector procedures, individual standards and mixtures of standards are injected to determine retention times and response factors for all compounds of interest, and values are recorded. If response factors vary more than ± two standard deviations and/or retention times vary ± 15 seconds, remedial action is instituted.

3. ECD-Gas Chromatography Halogenated Hydrocarbon Calibration

Calibrations and linearity determinations, similar to those described above, are completed for chlorinated hydrocarbon analyses. As with FID procedures, individual standards and mixtures of standards (such as PCBs) are injected to determine retention times and response factors for all compounds of interest, and values are recorded. Remedial action is instituted if necessary.

SECTION V

GAS CHROMATOGRAPHY PROGRAM

The following section presents the initial parameters and run-programmed modifications which are necessary for analyzing each of the types of contaminants in the Bioreclamation Program.

A. PREPARING FOR ANALYSIS

Column: SE54-30N 30 meter fused silica capillary.

Column pressure: 10 to 15 psi using He as the capillary inlet carrier gas (flow rate 1.5 ml/min).

Injection: 1 μl splitless, using auto-injection sampler.

Split vent: 30-40 mls./min.

Septum purge: 1-1.5 ml/min.

ECD makeup gas: argon/10% methane @ 30-40 ml/min.

FID makeup gas: hydrogen @ 30-40 ml/min.
zero air @ 200-300 ml/min.
nitrogen @ 30 ml/min.

Recorder settings: chart speed @ 0.50 cm/min.
zero @ 20% full scale deflection.
slope sensitivity @ 0.30.
integrator area reject @ 1,000,000,000 area counts

B. RUN PROGRAM FOR A SOIL MICROCOSM

TIME (minutes)	Action
0	Oven Temp at 45°C
0.75	Inlet purge (backflush) beings
3	Integrator Area Reject reset to 100 area counts (i.e., solvent peak has eluted)
5	Oven Temp assumes rate of 3.5°C/minute
72	Oven Temp reaches 280°C and the temperature stabilizes
80	Stop run

SECTION VI

GC/MS ANALYSIS OF PURGEABLE ORGANICS (VOAs)

A. SEDIMENT/SOIL SAMPLES METHODS

An inert gas is bubbled through a mixture of a 5 ml sample contained in a specially designed purging chamber at elevated temperatures. The purgeables are efficiently transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent column where the purgeables are trapped. After purging is completed, the sorbent column is heated and backflushed with the inert gas to desorb the purgeables onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the purgeables which are then detected with a mass spectrometer.

B. INTERFERENCES

Impurities in the purge gas, organic compounds out-gassing from the plumbing ahead of the trap, and solvent vapors in the laboratory account for the majority of contamination problems. The analytical system is demonstrated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks. The use of non-TFE tubing, non-TFE thread sealants, or flow controllers with rubber components in the purging device is avoided.

Contamination by carry over can occur whenever high level and low level samples are sequentially analyzed. To reduce carry over, the purging device and sampling syringe is rinsed with reagent water between sample analyses. Whenever an unusually concentrated sample is encountered, it is followed by an analysis of reagent water to check for cross contamination. Because the trap and other parts of the system are also subject to contamination, a blank is run between every sample, baking out the system and eliminating this source of carry over.

C. APPARATUS AND MATERIALS

Purge and trap device. The purge and trap device consists of three separate pieces of equipment; the sample purger, trap and the desorber.

The sample purger is designed to accept 5 ml samples with a water or slurry consistency. Inert gas is bubbled through the sample at a rate of 30 ml/min for 12 minutes. The purge gas is then transferred through Teflon purge lines where it is introduced to the base of the trap.

The trap is at least 25 cm long and has an inside diameter of 0.105 inch. The trap is packed to contain the following minimum lengths of absorbents: 1.0 cm of methyl silicone coated packing (3% OV-1 on Chromosorb W or equivalent), 15 cm of 2,6-diphenylene oxide polymer (Tenax-GC 60/80 mesh) and 8 cm of silica gel (Davison Chemical, 35/60 mesh, grade 15, or equivalent).

The desorber is capable of rapidly heating the trap to 180°C. The polymer section of the trap is not heated higher than 180°C and the remaining sections do not exceed 220°C.

Gas chromatograph. An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, and gases.

Column. 6 ft long x 0.1 in ID glass, packed with 1% SP-1000 on Carbopack B (60/80 mesh) or equivalent.

Mass spectrometer. Capable of scanning from 35 to 275 amu every 2 sec, utilizing 70 volts (nominal) electron energy in the electron impact ionization mode and producing a mass spectrum which meets all the criteria in Table E-1 when 50 ng of 4-bromofluorobenzene (BFB) is injected through the gas chromatograph inlet.

TABLE E-1. CHARACTERISTIC IONS FOR SURROGATE AND INTERNAL STANDARDS FOR VOLATILE ORGANIC COMPOUNDS

Compound	Primary Ion	Secondary Ion(s)
SURROGATE STANDARDS		
4-Bromofluorobenzene	95	174, 176
1,2-Dichloroethane d-4	102	--
Toluene d-8	98	70, 100
INTERNAL STANDARDS		
Bromochloromethane	128	49, 130, 51
1,4-Difluorobenzene	114	63, 88
Chlorobenzene d-5	117	82, 119

Data system. A computer system interfaced to the mass spectrometer allows the continuous acquisition and storage on machine readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer has software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP). Software is also available that allows integrating the abundance in any EICP between specified time or scan number limits.

D. GC/MS CALIBRATION

Instrument calibration is accomplished daily and checked every eight hours. The calibration compound FC 43 is used to set mass assignments. The mass stability criteria is ± 0.05 amu or better over an 8-hour period.

E. TUNING AND GC/MS MASS CALIBRATION FOR ANALYSIS OF PURGEABLE ORGANICS

Prior to initiating any on-going data collection, it is necessary to establish that a given GC/MS meets the standard mass spectral abundance criteria. This is accomplished through the analysis of p-Bromofluorobenzene (BFB). The ion abundance criteria for the calibration compound MUST be met before any samples, blanks or standards can be analyzed.

The GC/MS system used for the analysis of volatile HSL compounds must be hardware tuned to meet the abundance criteria listed in Table E-2 for a maximum of a 50 nanogram injection of BFB. This criterion must be demonstrated daily or for each 12-hour time period, postacquisition manipulation of ion abundance is NOT performed.

TABLE E-2. BFB KEY IONS AND ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
50	15.0 - 40.0 percent of the base peak
75	30.0 - 60.0 percent of the base peak
95	base peak, 100 percent relative abundance
96	5.0 - 9.0 percent of the base peak
173	less than 1.00 percent of the base peak
174	greater than 50.0 percent of the base peak
175	5.0 - 9.0 percent of mass 174
176	greater than 95.0 percent but less than 101.0 percent of mass 174
177	5.0 - 9.0 percent of mass 176

Note: Whenever the Laboratory takes corrective action which may change or affect the tuning criteria for BFB (e.g., ion source cleaning or repair, etc.), the tune must be verified, irrespective of the 12-hour tuning requirements.

BFB criteria MUST be met before any samples, sample extracts, blanks or standards are analyzed. Any samples analyzed when tuning criteria have not been met may require reanalysis.

Definition: The 12-hour time period for tuning and calibration criteria begins at the moment of injection of the BFB analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours according to the system clock.

F. GC/MS OPERATING CONDITIONS

The performance tests require the following instrumental parameters:

Electron Energy:	70 Volts (nominal)
Mass Range:	35 - 275 amu
Scan Time:	to give at least 5 scans per peak but not to exceed 7 seconds per scan.

G. QUALITATIVE ANALYSIS

The target compounds listed in the Hazardous Substances List (HSL), Table E-3, are identified by an analyst competent in the interpretation of mass spectra by comparison of the sample mass spectrum to the mass spectrum of a standard of the suspected compound. Two criteria are satisfied to verify the identifications: (1) elution of the sample component at the same GC relative retention time as the standard component, and (2) correspondence of the sample component and standard component mass spectra.

For establishing correspondence of the GC relative retention time (RRT), the sample component RRT is compared within ± 0.06 RRT units of the RRT of the standard component. For reference, the standard is run on the same shift as the sample. If coelution of interferring components prohibited accurate assignment of the sample component RRT from the total ion chromatogram, the RRT was assigned by using extracted ion current profiles for ions unique to the component of interest.

For comparison of standard and sample component mass spectra, mass spectra obtained on the GC/MS are required. Once obtained, these standard spectra are used for identification purposes only if the GC/MS meets the daily tuning requirements for BFB. These standard spectra are obtained from the run used to obtain reference RRTs.

TABLE E-3. CHARACTERISITC IONS FOR VOLATILE HSL COMPOUNDS

Parameter	Primary Ion	Secondary Ion(s)
Chloromethane	50	52
Bromomethane	94	96
Vinyl chloride	62	64
Chloroethane	64	66
Methylene chloride	84	49, 51, 86
Acetone	43	58
Carbon disulfide	76	78
1,1-Dichloroethene	96	61, 98
1,1-Dichloroethane	63	65, 83, 85, 98, 100
trans-1,2-Dichloroethene	96	61, 98
Chloroform	83	85
1,2,-Dichloroethane	96	62, 64, 100
2-Butanone	72	57
1,1,1-Trichloroethane	97	99, 117, 119
Carbon tetrachloride	117	119, 121
Vinyl acetate	86	--
Bromodichloromethane	127	83, 85, 129
1,1,2,2-Tetrachloroethane	168	83, 85, 131, 133, 166
1,2-Dichloropropane	112	63, 65, 114
trans-1,3,-Dichloropropene	75	77
Trichlorethene	130	95, 97, 132
Dibromochloromethane	127	129, 208, 206
1,1,2-Trichloroethane	97	83, 85, 99, 132, 134
Benzene	78	--
cis-1,3-Dichloropropene	75	77
2-Chloroethyl vinyl ether	106	63, 65
Bromoform	173	171, 175, 250, 252, 254, 256
2-Hexanone	100	58, 57
4-Methyl-2-pentanone	100	58
Tetrachloroethene	164	129, 131, 166
Toluene	92	91
Chlorobenzene	112	114
Ethyl benzene	106	91
Stryene	104	78, 103
Total xylenes	106	91

The requirements for qualitative verification by comparison of mass spectra are as follows:

(1) All ions present in the standard mass spectra at a relative intensity greater than 10% (most abundant ion in the spectrum equals 100%) must be present in the sample spectrum.

(2) The relative intensitites of ions specified in (1) must agree within plus or minus 20% between the standard and sample spectra. (Example: For an ion with an abundance of 50% in the standard spectra, the corresponding sample abundance must be between 30 and 70 percent).

(3) Ions greater than 10% in the sample spectrum but not present in the standard spectrum must be considered and accounted for by the analyst making the comparison.

H. QUANTITATIVE ANALYSIS

HSL components identified are quantified by the internal standard method. The internal standard used is the one nearest the retention time to that of a given analyte. The characteristic ions of analytes listed in Tables E-1 and E-3 are used. The response factor (RF) from the daily standard analysis is used to calculate the concentration in the sample. Use the response factor and the following equation:

$$\text{Concentration } (\mu g/L \text{ or } \mu g/kg = \frac{(A_x)\ (I_s)}{(A_{is})\ (RF)}\ (Vo)$$

Where:

A_x = Area of the characteristic ion for the compound to be measured

A_{is} = Area of the characteristic ion for the specified internal standard

I_s = Amount of internal standard injected in nanograms (ng)

V_o = Volume of water purged in milliliters (mL) (take into account any dilutions) or mass of sediment/soil purged in grams (gm).

Raw area counts are used for both the compound to be measured and the internal standard. A response factor (RF) of one (1) is assumed. The value from this quantitation is qualified as estimated. This estimated concentration is calculated for all tentatively identified compounds as well as those identified as unknowns.

Xylenes (o, m, and p - isomers) are to be reported as total xylenes. Since o- and p-xylene overlap, the xylenes must be quantitated versus m-xylene. The concentration of all xylene isomers must be added together to give the total.

Surrogate standard recoveries are calculated on all samples, blanks and spikes. Recovery is calculated in the following way:

$$\text{Percent Surrogate Recovery} = \frac{Q_d}{Q_a} \times 100\%$$

where: Q_d = quantity determined by analysis

Q_a = quantity added to sample

SECTION VII

GC/MS ANALYSIS OF EXTRACTABLES

A. GAS CHROMATOGRAPH/MASS SPECTROMETER SYSTEM

Gas chromatograph. An analytical system complete with a temperature programmable gas chromatograph suitable for split injection and all required accessories including syringes, analytical columns, and gases.

Column. 30 m x 0.25 m ID (or 0.32 mm) bonded-phase silicone coated fused silica capillary column (J&W Scientific DB-5 or equivalent). A film thickness of 1.0 micron is recommended because of its larger capacity. A film thickness of 0.25 micron may be used.

Mass Spectrometer. Capable of scanning from 35 to 475 amu every 1 second or less, utilizing 70 volts (nominal) electron energy in the electron impact ionization mode and producing a mass spectrum which meets all required criteria when 50 ng of decaflurotriphenylphosphine (DFTPP) is injected through the GC inlet.

NOTE: DFTPP criteria must be met before any sample extracts are analyzed.

Data system. A computer system is interfaced to the mass spectrometer that allows the continuous acquisition and storage on machine readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer has software that allows searching any GC/MS data file for ions of a specific mass and plotting such ion abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP). Software is available that allows integrating the abundance in any EICP between specified time or scan number limits.

B. GC/MS CALIBRATION

Instrument calibration is accomplished daily and checked every 8 hours. The calibration compound FC 43 is used to set mass assignments. The mass stability criteria is ± 0.05 amu or better over an 8 hour period.

C. TUNING AND GC/MS MASS CALIBRATION FOR ANALYSIS OF EXTRACTABLES

Great care is taken to maintain the integrity of all standard solutions. All standard solutions are stored at 4°C or less in screw cap amber bottles with teflon liners. Fresh standards are prepared every 6 months at a minimum.

Prior to initiating any ongoing data collection, it is necessary to establish that a given GC/MS meets the standard mass spectral abundance criteria. This is accomplished through the analysis of decafluorotriphenylphosphine (DFTPP). The ion abundance criteria for the calibration compound MUST be met before any samples, blanks or standards can be analyzed.

The GC/MS system used for the analysis of extractables must be hardware tuned to meet the abundance criteria listed in Table E-4 for a 50 ng injection of DFTPP. DFTPP may be analyzed separately or as part of the calibration standard. The criteria must be demonstrated daily or for each 12 hour period. DFTPP must be injected to meet this criterion. Post-acquisition manipulation of ion abundance is NOT acceptable.

TABLE E-4. DFTPP KEY IONS AND ION ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
51	30.0 - 60.0 percent of mass 198
68	less than 2.0 percent of mass 69
70	less than 2.0 percent of mass 69
127	40.0 - 60.0 percent of mass 198
197	less than 1.0 percent of mass 198
198	base peak, 100 percent relative abundance
199	5.0 - 9.0 percent of mass 198
275	10.0 - 30.0 percent of mass 198
365	greater than 1.00 percent of mass 198
441	present but less than mass 443
442	greater than 40.0 percent of mass 198
443	17.0 - 23.0 percent of mass 442

NOTE: Whenever the Laboratory takes corrective action which may change or affect the tuning criteria for DFTPP (e.g., ion source cleaning or repair, etc.), the tune must be verified irrespective of the 12-hour tuning requirements.

DFTPP criteria MUST be met before any samples, sample extracts, blanks or standards are analyzed. Any samples analyzed when tuning criteria have not been met may require reanalysis.

Definition: The 12-hour time period for tuning and calibration criteria begins at the moment of injection of the DFTPP analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours according to the system clock.

D. GC/MS ANALYSIS

The following instrumental parameters are required for all performance tests and for all sample analyses:

Electron Energy - 70 volts (nominal)
Mass Range - 35 to 475 amu
Scan Time - 1 second per scan

The GC/MS analysis of hexane extracts is carried out using a 30 m x 0.32 mm i.d. DB5 fused silica capillary column directly coupled to the mass spectrometer ion source. Column head pressure is maintained with helium carrier gas at 10 PSI. A one microliter aliquot of the extract is split injected into an injection port maintained at 275°C (split ratio is 10:1). The analysis is conducted using a temperature program of 30°C for 5 minutes then 275°C at 3.5 degrees/min; the upper temperature is held until the end of the analysis. The mass spectrometer is scanned over a mass range of 35-475 at a rate of 1 second per scan. Typical alkane data files usually contain 5,500 scans of acquired data for each sample extract analysis. For B/N/As files, 3000 scans of acquired data are a typical quantity.

E. QUALITATIVE ANALYSIS

Base/Neutrals and Acids (B/N/As). The B/N/As analysis is conducted similar to the VOA analysis. The characteristic ions of analytes listed in Table E-5 are used. Target compounds are listed in a Hazardous Substance List (HSL) library. The unknown sample compounds are identified by comparison of the sample mass spectra to that of a standard run the same day. Two critiera must be met to verify the identification: 1) the mass spectrum of the sample and standard must match reasonably well with all major mass peaks present in the unknown spectra, and 2) the retention time must match within ± 0.1 minutes of the standard.

TABLE E-5. CHARACTERISTIC IONS FOR SEMIVOLATILE HSL COMPOUNDS

Parameter	Primary Ion	Secondary Ion(s)
N-Nitrosodimethylamine	42	74, 44
Phenol	94	65, 66
Aniline	93	66
bis (-2-Chloroethyl) Ether	93	63, 95
2-Chlorophenol	128	64, 130
1,3-Dichlorobenzene	146	148, 113
1,4-Dichlorobenzene	146	148, 113
Benzyl Alcohol	108	79, 77
1,2-Dichlorobenzene	146	148, 113
2-Methylphenol	108	107
bis (2-chloroisopropyl) Ether	45	77, 79
4-Methylphenol	108	107
N-Nitroso-Di-Propylamine	130	42, 101
Hexachloroethane	117	201, 199
Nitrobenzene	77	123, 65
Isophorone	82	95, 138
2-Nitrophenol	139	65, 109
2,4-Dimethylphenol	122	107, 121
Benzoic Acid	122	105, 77
bis (-2-Chloroethoxy) Methane	93	95, 123
2,4-Dichlorophenol	162	164, 98
1,2,4-Trichlorobenzene	180	182, 145
Naphthalene	128	129, 127
4-Chloroaniline	127	129
Hexachlorobutadiene	225	223, 227
4-Chloro-3-Methylphenol	142	107, 144
2-Methylnapthalene	142	141
Hexachlorocyclopentadiene	237	235, 272
2,4,6-Trichlorophenol	196	198, 200
2,4,5-Trichlorophenol	196	198, 200
2-Chloroaphthalene	162	164, 127
2-Nitroaniline	138	92, 65
Dimethyl Phthalate	163	194, 164
Acenaphthylene	152	151, 153
3-Nitroaniline	138	108, 92
Acenaphthene	154	152, 153
2,4-Dinitrophenol	184	63, 154
4-Nitrophenol	65	139, 109
Dibenzofuran	204	206, 141
2,4-Dinitrotoluene	165	63, 182

(continued)

TABLE E-5. (CONTINUED)

Parameter	Primary Ion	Secondary Ion(s)
2,6-Dinitrotoluene	165	89, 121
Diethylphthalate	149	177, 150
4-Chlorophenyl-phenylether	204	206, 141
Fluorene	166	165, 167
4-Nitroaniline	138	92, 65
4,6-Dinitro-2-Methylphenol	198	182, 77
N-Nitrosodiphenylamine	169	168, 167
4-Bromophenyl-phenylether	284	142, 249
Hexachlorobenzene	248	250, 141
Pentachlorophenol	266	264, 268
Phenathrene	178	179, 176
Anthracene	178	179, 176
Di-N-Buthylphthalate	149	150, 104
Fluoranthene	202	101, 100
Benzidine	184	92, 85
Pyrene	202	101, 100
Butylbenzylphthalate	149	91, 206
3,3'-Dichlorobenzidine	252	254, 126
Benzo (a)Anthracene	228	229, 226
bis(2-Ethylhexyl)Phthalate	149	167, 279
Chrysene	228	226, 229
Di-N-Octyl Phthalate	149	-
Benzo(b)Fluoranthene	252	253, 125
Benzo(k)Fluoranthene	252	253, 125
Benzo(a)Pyrene	252	253, 125
Indeno (1,2,3-cd) Pyrene	276	138, 227
Dibenz(a, h) Anthracene	278	139, 279
Benzo(g, h, i)Perylene	276	138, 277

Compounds that cannot be identified using the reference library are placed through an unknown search. The computer attempts compound identification by searching its master library for best fit and purity. If no match is found, the compound is considered an unknown.

Alkanes are identified by comparing sample retention times of FID-GC analyses with those from GC/MS analyses. An alkane standard, consisting of n-alkanes from nC-8 through nC-32 plus pristane and phytane, is analyzed by GC/MS. Subsequently, a Day 1 sample is spiked with this standard and analyzed to precisely identify n-alkane peaks in the sample. All retention times for n-alkanes at intermediate peaks are converted to KOVAT indices and compared with the KOVAT indices derived from the computer data reduction of FID-GC analyses.

Several GC/MS data analysis programs are utilized to identify the intermediate peaks present between the previously identified n-alkane peaks. The ANNIE program attempts identification by running an unknown search on selected (scan list) peaks in the chromatograph. This program gives the four best spectral matches for each peak selected. The AHA program runs a selected scan list of unknowns, and yields one "hit" for each unknown along with amount of library response factor, purity and fit data, but no spectrum. The PAYNE program is a screening method used to search for selected compounds in the approximate scan range where they are expected to elute. This third program picks characteristic ions for the selected compounds and gives the area (amount) present over the selected scan range.

D. QUANTITATIVE ANALYSIS

HSL extractable components identified are quantified by first correlating their peak retention times with those of FID-GC analyzed samples run on an identical temperature program. The FID-GC peaks are then quantified relative to the dry sample weight by the SAIC GC Data Reduction Program.

SECTION VIII

CORRECTIVE ACTION

The need for corrective action comes from several sources: equipment malfunction; failure of internal QA/QC checks; failure of performance or system audits; and noncompliance with QA requirements. Each task in the experimental design will define what the acceptable limits are beyond which corrective action must be implemented.

If measurement equipment or analytical methods fail QA/QC checks, the problem will immediately be brought to the attention of the JRB Laboratory Task Manager and QA Officer. If failure is due to equipment malfunction, the equipment will be repaired, precision and accuracy will be reassessed, and the analyses will be rerun.

APPENDIX F

LABORATORY PERMEABILITY STUDIES

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TABLE F-1. METHODS USED FOR GROUNDWATER ANALYSIS

Component	Method*
Na	325B
K	322B
Ca	311A
Mg	318A
Fe	315A
Mn	319A
Cl^-	407A
HCO_3	306C
SO_4	426C
PO_4	424E
NO_3	418C
NH_4	417C
EC	205
pH	423

* Standard Methods (1985), (Reference 2)
References listed in Appendix F.

TABLE F-2. STANDARD METHODS USED IN ANALYSIS OF SOIL

Parameters	Standard Method
Particle size	ASTM D 422 (Reference 1)
Water content	ASTM D 2216 (Reference 1)
Particle density	ASTM D 854 (Reference 1)
Bulk density	ASTM D 1556 (Reference 1)
Soil reaction (pH)	Black (1965) 60-34 (Reference 3)
Electrical conductivity (EC)	Black (1965) Proc. 62-2.2.3 (Reference 3)
Soluble ions	
Na	AA*, direct aspiration. EPA (1979) (Reference 4)
K	AA*, direct aspiration. EPA (1979) Method 258.1 (Reference 4)
Ca	AA*, direct aspiration. EPA (1979) Method 215.1 (Reference 4)
Mg	AA*, direct aspiration. EPA (1979) Method 242.1 (Reference 4)
HCO_3	Black (1965) 62-3.4.2 (Reference 3)
Cl	Black (1965) 62-3.5.2 (Reference 3)
SO_4	Turbidmetric. EPA (1979) (Reference 4)
CEC calcareous samples	1. Page (1982) 8.3 (Reference 6)
CEC noncalcareous samples	2. Jackson (1958) (Reference 5)
Exchangeable bases	1. Total Extractable by Page (1982)
(Ca, Mg, K, Na	Proc. 9-3.1.2.3. (Reference 6)
1:1 (Soil:Water)	2. Black (1965) 62-1.3.2 (Reference 3)
	Difference between (1) and (2) in exchangeable bases
Mn	AA*, direct aspiration. EPA (1979) Method 243.1 (Reference 4)
Fe	Standard Methods (1985) Method 303A (Reference 2)
Extractable Reduced Fe & Mn	Page (1982) 17.3 (Reference 6)
PO_4-P	Page (1982) 24-5.3 (Reference 6)
NO_3-N	Page (1982) 33-8.3 (Reference 6)
NH_4-N	Page (1982) 33-7.3 (Reference 6)
Gypsum	USDA Method 7 (Reference 7)
Neutralization Potential	USDA Method 3 (Reference 7)

**AA - Atomic Absorption spectrometry
References listed in Appendix F.

TABLE F-3. METHODS OF ANALYSIS FOR CONSTITUENTS IN LEACHATE FROM THE PERMEAMETERS

Leachate Constitutents	Method of Analysis
Chloride	Page et al (1982) 26-3.4 (Reference 6)
Water soluble phosphate	Standard Methods (1985) (Reference 2) Methods number 424B and 424E
Acid soluble phosphate	Standard Methods (1985) (Reference 2) Methods number 424B and 424E
Peroxide	EM Quant - Peroxide Test. Aldrich Chemical Co. Cat. #10011-1

References listed in Appendix F.

TABLE F-4. ANALYSIS OF GROUNDWATER FOR CATIONS, TOTAL IRON AND MANGANESE

Sample	Na	K	Ca	Mg (mg/l)	Fe	Mn
KWB&A	15	2	89	11	0.04	0.02
JRB&A	33	2.5	165	17	0.11	0.37

TABLE F-5. ANALYSIS OF GROUNDWATER FOR ANIONS, NUTRIENTS, ELECTRICAL CONDUCTIVITY AND pH

Sample	Cl^-	HCO_3^-	SO_4^{-2}	PO_4-P (mg/l)	NO_3-N	NH_4-N	EC (mhos/cm)	pH
KWB&A	20	185	15	<0.1	0.01	4.5	0.50	7.5
JRB&A	22	566	52	<0.1	0.04	<0.1	-	7.1

TABLE F-6. ANALYSIS OF SOIL FOR SOLUBLE AND EXCHANGEABLE CATIONS

Sample	Soluble Cations (meq/l)				Exchangeable Cations (meq/l)			
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}
A1	3.7	0.5	0.5	0.1	39.5	1.4	0.2	≤0.1
A2	2.7	0.4	0.7	0.1	38.3	1.5	0.2	≤0.1
A3	2.2	0.5	0.7	0.1	36.5	1.5	0.2	≤0.1
JRB&A	2.1	0.3	1.0	0.1	39.5	1.8	0.2	≤0.1

TABLE F-7. ANALYSIS OF SOIL FOR ANIONS, ALKALINITY, CEC, pH, EC, AND GYPSUM CONTENT

Sample	Cl^{-1} (meq/l)	HCO_3^{-1} (meq/l)	SO_4^{-2} (meq/l)	Alkalinity (meq/100g)	CEC (meq/100g)	pH	EC (mhos/cm)	Gypsum (%)
A1	0.2	2.4	2.0	868	21.4	8.24	0.34	≤0.1
A2	0.2	2.0	0.8	915	19.1	8.36	0.23	≤0.1
A3	0.4	2.1	0.6	880	19.2	8.46	0.24	≤0.1

TABLE F-8. ANALYSIS OF SOIL FOR TOTAL METALS, REDUCED METALS AND NUTRIENTS

Sample	Total Metals		Reduced Metals		NH_4-N (mg/l)	NO_3-N (mg/l)
	Fe (mg/l)	Mn (mg/l)	Fe (mg/l)	Mn (mg/l)		
A1	28800	640	-	-	4.4	15.4
A2	30000	600	-	-	2.6	8.8
A3	29600	354	-	-	2.4	8.6
A4	-	-	7.6	8.7	-	-
JRB&A	28400	410	3.4	3.7	3.0	3.1

TABLE F-9. PERMEABILITY VALUES AND NUTRIENT SOLUTION BREAKTHROUGH DATA SOIL SAMPLE NUMBER ONE

	Phosphate				Chloride		H_2O_2		Permeability
Pore	Water	Soluble	Acid	Soluble					
Volume	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(cm/sec)
-1.14	<0.1	0.00	<0.1	0.00	11.5	0.06	0	0	1.6×10^{-6}
0.80	<0.1	0.00	<0.1	0.00	12.2	0.06	0	0	2.0×10^{-6}
0.44	<0.1	0.00	<0.1	0.00	12.1	0.06	0	0	1.9×10^{-6}
0.00	<0.1	0.00	<0.1	0.00	12.1	0.06	0	0	1.9×10^{-6}
0.25	3.4	0.08	3.9	0.07	40.0	0.20	1	0.01	1.0×10^{-6}
0.50	12.4	0.29	13.1	0.23	56.0	0.28	1	0.01	1.0×10^{-6}
0.73	17.5	0.40	17.9	0.31	118.0	0.59	1	0.01	7.7×10^{-7}
1.06	18.0	0.42	19.6	0.34	145.4	0.73	1	0.01	9.2×10^{-7}
1.39	24.8	0.57	27.8	0.34	165.6	0.83	3	0.03	9.1×10^{-7}
1.79	25.8	0.60	27.8	0.54	172.9	0.86	20	0.20	6.8×10^{-7}
2.21	26.3	0.61	31.1	0.51	-	-	20	0.20	8.3×10^{-7}
2.40	25.5	0.59	29.9	0.45	-	-	25	0.25	3.8×10^{-7}
2.51	25.5	0.59	25.5	0.40	-	-	25	0.25	2.9×10^{-7}
2.58	23.7	0.55	22.9	0.30	-	-	25	0.25	1.5×10^{-7}
2.81	16.0	0.38	17.0	0.33	-	-	3	0.03	8.5×10^{-8}
3.00	19.0	0.44	19.0	0.37	-	-	30	0.30	6.5×10^{-7}
3.30	21.3	0.49	21.0	0.33	-	-	30	0.30	5.0×10^{-7}
3.64	7.1	0.16	19.7	0.32	-	-	30	0.30	5.9×10^{-7}

* Concentration of the constitutents in the leachate (C) divided by the concentration in the nutrient solution (Co).

TABLE F-10. PERMEABILITY VALUES AND NUTRIENT SOLUTION BREAKTHROUGH FOR SOIL SAMPLE NUMBER TWO

	Phosphate				Chloride		H_2O_2		Permeability
Pore	Water	Soluble	Acid	Soluble					
Volume	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(mg/l)	(C/C_o)*	(cm/sec)
-0.91	<0.1	0.00	<0.1	0.00	8.5	0.04	0	0	9.1×10^{-7}
-0.58	<0.1	0.00	<0.1	0.00	9.5	0.05	0	0	1.0×10^{-6}
0.00	<0.1	0.00	<0.1	0.00	9.5	0.05	0	0	1.4×10^{-6}
0.21	2.5	0.06	0.1	0.00	40.0	0.20	2	0.02	6.6×10^{-7}
0.54	8.6	0.20	8.0	0.14	97.7	0.49	1	0.01	9.5×10^{-7}
0.77	0.24	0.24	10.3	0.18	127.0	0.64	1	0.01	5.6×10^{-7}
0.98	11.8	0.27	11.2	0.20	138.3	0.69	1	0.01	4.6×10^{-7}
1.20	13.4	0.31	13.5	0.24	140.0	0.70	1	0.01	4.5×10^{-7}
1.56	17.8	0.41	16.0	0.28	141.6	0.71	1	0.01	4.6×10^{-7}
1.96	24.2	0.56	19.1	0.33	154.4	0.77	1	0.01	5.8×10^{-7}
2.39	27.5	0.64	21.5	0.38	156.6	0.78	20	0.20	6.4×10^{-7}
2.83	27.5	0.64	28.7	0.50	173.1	0.87	40	0.40	8.8×10^{-7}
3.17	26.9	0.62	29.5	0.51	171.8	0.86	30	0.30	5.4×10^{-7}

* Concentration of the constitutents in the leachate (C) divided by the concentration in the nutrient solution (Co).

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APPENDIX G

GEOHYDROLOGIC MODEL RESULTS

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TABLE G-1. INJECTION/EXTRACTION SYSTEM WELL LOCATIONS AND INITIAL FLOW RATES

Grid Distance (feet)		Injection (I)/ Extraction (P) Rate (ft.^{3}/day)
X	Y	
248	222	30 (P)
263	207	30 (P)
263	237	30 (P)
278	192	30 (P)
278	222	40 (P)
278	252	30 (P)
293	207	30 (P)
293	237	30 (P)
308	222	30 (P)
263	222	70 (I)
278	207	70 (I)
278	237	70 (I)
293	222	70 (I)

TABLE G-2. WATER LEVEL CHANGES IN FEET AT GRID POINTS AFTER THE START OF INJECTION-EXTRACTION SYSTEM* (ELAPSED TIME = ONE DAY)

	150	200	225	248.25	255	263.25	270	278.25	293.25	308.25	330	350	375
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
175	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
192.25	0.00	0.00	0.00	0.00	0.02	0.06	0.25	2.73	0.06	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.02	0.13	0.33	-0.04	-0.52	0.33	0.02	0.00	0.00	0.00
207.25	0.00	0.00	0.00	0.06	0.25	2.68	-0.28	-4.73	2.69	0.06	0.00	0.00	0.00
222.25	0.00	0.00	0.00	2.73	-0.25	-4.73	-0.50	2.70	-4.73	2.74	0.00	0.00	0.00
237.25	0.00	0.00	0.00	0.06	0.25	2.69	-0.28	-4.73	2.70	0.05	0.00	0.00	0.00
252.25	0.00	0.00	0.00	0.00	0.01	0.06	0.26	2.74	0.05	0.00	0.00	0.00	0.00
260	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.27	0.01	0.00	0.00	0.00	0.00
275	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Grid distances in feet
Well locations are shown in Table G-1; negative values indicate water level rise

TABLE G-3. WATER LEVEL CHANGES IN FEET AT GRID POINTS AFTER THE START OF INJECTION-EXTRACTION SYSTEM* (ELAPSED TIME = 10 DAYS)

	150	200	225	248.25	255	263.25	270	278.25	293.25	308.25	330	350	375
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	0.00	0.00	0.00	0.02	0.03	0.04	0.04	0.05	0.04	0.02	0.00	0.00	0.00
175	0.00	0.00	0.03	0.12	0.16	0.25	0.33	0.38	0.24	0.11	0.03	0.01	0.00
192.25	0.00	0.01	0.08	0.23	0.23	0.31	0.46	2.86	0.31	0.23	0.09	0.02	0.00
200	0.00	0.02	0.12	0.28	0.33	0.25	-0.54	-1.27	0.29	0.28	0.12	0.03	0.00
207.25	0.00	0.02	0.17	0.31	0.23	2.21	-1.49	-4.98	2.26	0.32	0.18	0.04	0.00
222.25	0.00	0.02	0.24	2.86	-0.88	-4.98	-2.28	1.95	-4.98	2.90	0.26	0.05	0.00
237.25	0.00	0.02	0.17	0.31	0.26	2.26	-1.44	-4.98	2.30	0.32	0.18	0.04	0.00
252.25	0.00	0.01	0.08	0.23	0.27	0.32	0.50	2.90	0.32	0.22	0.09	0.02	0.00
260	0.00	0.01	0.05	0.17	0.23	0.35	0.34	0.77	0.34	0.17	0.05	0.01	0.00
275	0.00	0.00	0.02	0.08	0.12	0.17	0.21	0.24	0.17	0.08	0.02	0.00	0.00
300	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.00
350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Grid distances in feet

Well locations are shown in Table G-1; negative values indicate water level rise

TABLE G-4. WATER LEVEL CHANGES IN FEET AT GRID POINTS AFTER THE START OF INJECTION-EXTRACTION SYSTEM* (ELAPSED TIME = 60 DAYS)

	150	200	225	248.25	255	263.25	270	278.25	293.25	308.25	330	350	375
100	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01
150	0.01	0.05	0.07	0.10	0.11	0.13	0.13	0.14	0.12	0.10	0.07	0.05	0.03
175	0.02	0.07	0.10	0.12	0.14	0.19	0.23	0.29	0.19	0.12	0.10	0.08	0.06
192.25	0.02	0.09	0.12	0.05	0.01	-0.05	0.06	2.56	-0.04	0.05	0.12	0.10	0.07
200	0.03	0.10	0.15	0.01	-0.06	-0.27	-1.09	-1.80	-0.22	0.01	0.15	0.11	0.07
207.25	0.02	0.11	0.13	-0.05	-0.27	1.70	-2.09	-5.00	1.75	-0.02	0.18	0.12	0.07
222.25	0.03	0.12	0.27	2.26	-1.41	-5.00	-2.40	1.06	-5.00	2.61	0.24	0.14	[illegible]
237.25	0.03	0.11	0.13	-0.04	-0.24	1.75	-2.04	-5.00	1.80	-0.03	0.13	0.12	0.07
252.25	0.02	0.09	0.12	0.05	0.02	-0.03	0.10	2.61	-0.03	0.06	0.12	0.10	0.08
260	0.02	0.08	0.11	0.09	0.10	0.16	0.22	0.54	0.15	0.09	0.11	0.09	0.05
275	0.02	0.07	0.09	0.12	0.14	0.18	0.21	0.23	0.13	0.12	0.10	0.07	0.04
300	0.01	0.04	0.07	0.09	0.10	0.11	0.11	0.12	0.11	0.09	0.07	0.05	0.03
350	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01

*Grid distances in feet
Well locations are shown in Table G-1; negative values indicate water level rise

APPENDIX H

FIELD MONITORING AND ANALYTICAL RESULTS

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TABLE H-1. RESULTS OF SOIL ORGANIC PRIORITY POLLUTANT ANALYSES

	SB-1	SB-2	SB-3	SB-4
Methylene Chloride	86	34	60	39
Bis (2-ethyl hexyl) phthalate	ND	490	ND	1200

Results express in µg/kg (ppb)
Samples collected 30 July - 3 August 1985
ND = None detected

TABLE H-2. RESULTS OF GROUNDWATER TEMPERATURE MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-23	25.5	25.0	28.0	26.0	27.0	27.0	27.5	28.5	28.0	28.0	29.5	28.0	28.0	27.0	27.0	-
6-17	48.9	34.5	48.8	36.4	38.9	34.2	39.9	47.8	38.1	31.4	26.9	29.3	29.6	20.8	22.3	22.1
6-19	48.9	38.0	36.6a	37.1	34.4a	36.8	35.5a	44.5	34.8a	28.0	30.1	28.4	27.1	21.0	22.5	22.2
6-27	46.3	28.7	36.8	36.7	36.4	34.2	36.5	45.3	39.2	28.4	28.2	29.3	29.4	20.9	22.2	22.2
7-1	35.4	28.9	32.8	29.5	31.3	29.2	33.7	31.0	33.5	28.2	30.3	28.2	26.8	24.8	30.7	-
7-5	28.1	26.9	27.0	28.1	27.5	28.4	28.8	29.6	27.3	26.1	25.9	25.6	28.8	22.9	24.0	-
7-8	38.1b	31.0b	26.9	34.8b	26.6	33.6b	26.6	35.2b	27.4	-	26.6	27.7	26.9	23.6	23.9	-
7-12	36.9b	29.9b	27.3	33.2b	27.3	34.3b	27.9	35.2b	28.8	27.2	25.0	26.7	26.1	22.3	23.2	23.4
7-16	29.8	28.3	34.9	27.0	30.2	26.6	29.8	26.9	30.0	29.8	29.1	31.8	30.7	23.4	24.7	24.8
7-18	30.6b	38.2b	28.2	30.5b	27.1	31.0b	27.3	34.7b	27.8	30.1	31.7	34.1	34.1	23.7	24.0	23.8
7-22	36.0b	28.8	37.3b	26.7	35.4b	26.6	37.1b	28.1	37.9b	28.2	27.2	31.2	31.4	23.6	24.7	-
7-25	32.0	27.3	29.9	26.1	29.3	26.2	29.5	26.6	30.1	27.3	26.0	26.9	27.1	23.4	24.2	24.1
7-30	34.0	29.1	29.8	28.8	32.9	34.8	35.2	34.7	37.7	27.0	27.3	29.1	28.6	23.9	24.5	24.8
8-3	32.8	29.9	29.7	29.0	31.2	33.3	34.7	35.1	35.0	27.0	27.2	29.1	28.3	23.9	24.5	24.8
8-6	31.0	29.0	28.9	28.8	30.2	31.5	32.6	33.1	32.8	27.0	27.1	28.5	28.1	23.8	24.6	25.0
8-8	28.5	26.9	28.7	28.4	27.2	26.6	27.4	27.1	27.8	33.7	30.4	30.5	31.7	25.3	26.3	-
8-12	-	27.3	38.0	27.7	36.9	27.7	38.4	30.5	39.7	31.5	31.0	33.1	37.8	24.1	24.0	24.4
8-14	-	27.1	40.6b	26.2	33.9b	26.9	34.0b	28.7	33.3b	29.3	30.9	30.6	31.2	23.5	23.2	-
8-20	-	28.1	31.6	27.0	33.6	27.6	27.4	27.7	37.6	26.3	33.2	34.9	37.0	24.8	24.5	24.7
8-22	30.4b	44.9b	28.4	36.3b	27.8	36.6b	27.5	38.6b	28.7	29.8	29.7	32.2	31.3	23.6	23.8	23.6
8-27	27.2	26.7	27.0	25.8	27.2	26.0	26.3	26.8	27.0	28.9	28.6	27.6	28.3	23.9	23.7	24.1
8-30	28.2	35.6b	26.6	31.1b	26.9	32.6b	26.7	39.1b	27.6	27.6	28.0	33.0	30.6	24.0	24.8	24.3
9-3	36.1	26.9	27.0	26.3	26.6	26.6	26.9	26.0	29.1	-	-	31.2	31.6	23.7	24.7	24.4
9-6	31.1b	32.8b	27.0	35.0b	27.4	35.9b	26.8	38.0b	34.2b	26.8	26.2	27.4	27.4	24.1	23.6	23.9

Temperature readings in °C

a Indicates pump was shut off the previous day
b Indicates pump was on at time of reading
- Reading not taken

TABLE H-3. RESULTS OF GROUNDWATER DISSOLVED OXYGEN MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
6-17	-	-	-	-	-	-	-	-	-	5.9	4.6	5.7	4.5	2.5	1.5	1.5
6-19	5.3	5.5	5.4a	4.0	4.7a	2.7	4.3a	4.6	4.0a	4.1	5.5	2.8	3.6	2.1	1.7	1.8
6-27	-	-	3.4	-	3.8	-	3.0	-	3.8	6.6	7.7	7.6	6.4	0.75	1.0	-
7-1	4.5	-	3.9	3.2	3.6	2.7	2.8	4.4	-	7.0	19.1	c	19.1	5.5	7.7	-
7-5	3.5	5.8	3.2	2.8	3.2	2.9	2.7	2.3	3.3	c	c	18.8	14.5	1.8	2.5	-
7-8	2.6b	6.3b	3.7	2.6b	3.1	2.4b	2.5	2.3b	2.1	d	c	17.6	c	1.5	2.5	-
7-12	1.4b	7.0b	2.9	2.5b	3.2	2.0b	3.7	3.1b	3.5	10.6	12.2	10.5	12.4	1.0	1.3	1.6
7-16	5.4	4.5	5.2	3.2	3.2	2.4	3.1	2.0	3.4	7.6	8.0	7.3	7.4	1.6	3.0	9.0
7-18	7.5b	5.6b	4.1	4.1b	3.3	2.7b	4.0	3.3b	3.8	8.6	8.1	7.3	7.2	1.6	1.3	1.5
7-22	7.3b	6.0	3.0b	3.3	2.1b	1.8	1.0b	3.4	2.6b	c	c	9.5	9.3	1.7	1.4	-
7-25	1.8	5.7	1.8	2.9	5.1	2.3	1.2	3.1	4.2	c	c	16.1	17.9	2.7	1.6	1.8
7-30	3.1	5.7	2.7	2.3	2.2	1.5	1.[illegible]	1.1	3.1	15.0	14.8	6.2	7.6	2.2	1.3	1.6
8-3	3.5	5.0	3.1	2.4	2.1	1.6	1.3	1.0	3.3	15.1	16.3	7.3	6.9	2.1	1.4	1.4
8-6	3.6	5.1	3.3	2.5	2.3	2.1	1.4	1.2	3.3	15.1	16.1	7.2	7.1	2.1	1.5	1.4
8-8	3.8	6.2	1.8	2.4	3.9	2.2	3.1	2.6	3.8	11.5	11.9	12.1	11.8	1.7	1.2	-
8-12	-	6.0	1.5	3.1	1.5	2.5	1.6	2.7	2.3	8.9	8.6	6.8	6.7	2.1	1.6	1.6
8-14	-	6.1	3.9b	4.1	3.6b	2.5	3.8b	3.0	4.0	8.3	8.6	8.9	8.5	1.4	0.9	-
8-20	-	3.5	3.7	4.6	4.1	2.6	4.2	2.8	3.3	9.6	10.1	8.2	7.2	1.3	0.9	1.1
8-22	6.1b	4.6b	3.4	3.2b	2.9	1.9b	3.0	1.9b	2.2	14.5	12.7	19.9	17.6	1.1	1.4	1.3
8-27	3.4	4.3	2.0	2.0	2.3	1.7	2.7	2.0	1.9	c	c	c	19.0	1.3	1.0	1.3
8-30	4.1	5.7b	1.7	2.4b	1.5	1.6b	1.6	1.6b	2.7	9.4	14.9	12.2	15.1	1.6	1.3	1.3
9-3	3.4	4.0	1.9	2.3	2.3	2.0	1.7	1.6	3.0	-	-	13.2	13.0	0.8	1.9	1.1
9-6	5.7b	5.5b	2.7	2.6b	2.9	1.3b	3.4	1.5b	2.9b	19.9	c	18.6	19.0	1.8	1.1	1.1

Dissolved oxygen readings in mg/l

-	Reading not taken
a	Indicates pump was shut off the previous day
b	Indicates pump was turned on during sample collection
c	Indicates reading was off scale
d	Indicates pump was shut off

H_2O_2 addition started 06-26-85

TABLE H-4. RESULTS OF GROUNDWATER CONDUCTIVITY MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-23	0.66	0.68	0.60	0.59	0.60	0.58	0.64	0.69	0.77	0.72	0.50	0.62	0.78	0.82	0.53	-
6-17	0.95	0.65	1.28	0.73	1.15	0.78	0.977	1.37	2.07	4.20	3.61	3.12	3.47	0.58	0.93	0.89
6-19	1.27	0.87	1.71	0.87	1.34	0.84	1.05	1.61	2.98	4.29	4.75	4.15	4.21	0.57	0.97	0.88
6-27	1.40	-	1.01	0.96	1.01	0.85	1.10	1.02	3.69	2.56	2.75	1.43	1.15	0.59	0.89	0.93
7-1	1.38	0.91	0.98	0.73	0.89	0.67	0.93	0.81	3.4	7.42	9.39	2.18	1.78	5.01	7.82	-
7-5	1.61	1.38	1.10	0.95	0.98	1.30	1.05	1.10	2.94	10.48	15.21	b	8.87	0.62	1.07	-
7-8	1.41a	0.99a	0.84	0.80a	0.77	0.87a	0.93	0.93a	1.67	-	17.20	b	11.20	0.54	0.97	-
7-12	1.44a	0.99a	0.80	0.74a	0.75	0.78a	0.80	0.86a	2.6	b	b	b	13.20	0.55	0.90	0.85
7-16	1.41	1.03	1.63	0.66	1.18	0.72	0.97	0.79	3.16	1.75	1.74	1.84	1.83	0.55	0.92	0.84
7-18	1.44a	1.10a	1.36	0.83a	1.11	0.68a	0.93	1.28a	2.7	0.86	0.91	1.06	0.92	0.52	0.96	0.80
7-22	1.67a	1.43	1.14a	0.68	1.20a	0.70	0.88a	0.72	2.99a	9.16	10.50	b	b	0.58	1.03	-
7-25	1.88	1.25	1.14	0.63	1.09	0.61	0.80	0.70	2.37	14.79	13.30	3.29	0.75	0.52	0.94	0.75
7-30	-	-	1.21	0.91	1.73	0.86	1.00	1.05	3.31	19.45	10.01	15.42	16.28	0.68	1.27	0.90
8-3	1.10	0.97	1.20	0.95	1.56	0.93	0.97	1.01	2.74	17.10	9.15	14.76	16.51	0.68	1.32	0.86
8-6	6.15	1.00	1.21	1.03	1.61	0.92	0.93	1.05	2.01	16.10	10.15	14.57	16.37	0.71	1.25	0.92
8-8	2.63	1.27	1.11	0.81	1.19	0.78	1.17	1.06	3.34	18.74	13.20	13.84	b	0.66	1.54	-
8-12	-	2.51	1.22	0.85	2.01	0.97	1.53	1.33	4.59	10.27	9.01	12.40	2.24	0.61	1.82	0.88
8-14	-	2.50	1.37a	0.85	2.48a	1.39	1.66a	1.32	4.36a	2.68	2.69	2.67	2.77	2.68	2.69	-
8-20	-	2.77	1.47	1.05	2.80	1.41	1.35	1.13	4.75	8.49	2.42	2.38	2.41	0.69	2.05	1.05
8-22	4.89	3.22a	1.77	1.31a	2.95	1.53a	1.43	2.29a	4.44	1.28	b	1.74	1.37	0.88	2.39	1.21
8-27	4.73	3.31	1.44	1.19	3.38	1.59	1.36	1.35	4.67	b	b	b	b	0.78	2.29	1.09
8-30	5.40	3.00a	1.71	1.39a	2.91	1.55a	1.50	2.19a	6.02	b	1.55	1.53	1.57	0.72	2.18	1.03
9-3	4.97	4.10	1.83	1.40	3.04	1.27	1.24	1.36	5.58	-	-	b	b	0.93	2.75	1.28
9-6	3.17a	2.56a	1.57	1.16a	2.24	1.19a	1.20	0.91a	3.42a	1.97	1.92	2.88	2.40	0.56	1.73	0.82

Conductivity readings ($(x10^3)$) umhos

a Indicates pump was on at time of sampling
b Indicates reading was off scale
- Reading not taken

TABLE H-5. RESULTS OF GROUNDWATER pH MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-23	6.40	6.80	6.70	>7.00	>7.00	>7.00	>7.00	>7.00	>7.00	7.20	7.20	7.20	7.00	7.20	7.20	-
6-17	6.98	7.27	7.05	7.49	7.18	7.07	6.88	7.02	7.25	6.75	6.75	6.84	6.84	7.18	6.70	6.72
6-19	6.63	7.01	6.32a	6.44	6.31a	6.35	6.13a	6.10	6.08a	6.80	6.97	6.88	6.88	7.08	6.69	6.77
6-27	6.34	-	6.13	6.20	6.07	6.13	5.93	6.14	5.83	6.92	6.93	6.97	7.01	7.16	6.86	6.79
7-1	6.23	6.55	6.48	6.45	6.46	6.35	6.16	6.22	6.08	6.89	6.80	6.58	6.67	6.70	6.35	-
7-5	6.28	6.38	6.42	6.40	6.51	6.21	6.34	6.28	6.27	6.90	6.95	6.69	6.81	6.67	6.12	-
7-8	6.00b	6.57b	6.44	6.30b	6.48	6.19b	6.24	6.10b	6.24	-	6.82	6.66	6.60	6.52	6.07	-
7-12	6.01b	6.64b	6.22	6.36b	6.34	6.22b	6.23	6.09b	6.25	7.05	6.88	6.82	6.80	6.60	6.06	6.23
7-16	6.63	6.88	6.42	6.85	6.42	6.48	6.32	6.33	6.25	6.67	6.71	6.95	6.90	6.82	6.37	6.58
7-18	6.39b	6.43b	6.29	6.36b	6.34	6.39b	6.22	6.09b	6.11	6.96	6.87	7.00	6.92	6.76	6.31	6.36
7-22	6.38b	6.26	6.12b	6.50	6.35b	6.34	6.11b	6.17	6.08b	6.91	6.92	6.88	6.85	6.67	6.38	-
7-25	6.58	6.59	6.37	6.48	6.43	6.52	6.28	6.41	6.25	7.37	7.35	7.26	7.48	7.30	6.84	6.93
7-30	-	-	7.34	7.39	6.62	6.72	6.52	6.57	6.57	7.50	7.65	7.37	7.36	7.12	6.79	6.95
8-3	6.93	7.41	7.50	7.40	6.63	6.73	6.36	6.62	6.59	7.50	7.69	7.53	7.49	7.01	6.90	6.97
8-6	6.91	7.45	7.47	7.50	6.73	6.70	6.61	6.68	6.65	7.39	7.61	7.57	7.53	7.01	6.91	6.99
8-8	6.91	7.28	7.11	7.29	6.95	6.86	6.65	6.74	6.65	6.78	6.84	6.75	6.82	6.29	6.31	-
8-12	-	6.96	6.73	6.98	6.57	6.56	6.40	6.49	6.29	6.97	7.02	6.98	7.40	6.60	6.48	6.80
8-14	-	6.54	6.61b	6.79	6.37b	6.53	6.46b	6.54	6.36b	7.36	7.46	7.74	7.31	6.90	6.55	-
8-20	-	6.85	6.76	6.87	6.60	6.63	6.75	6.67	6.57	6.78	7.29	7.65	7.41	6.53	6.31	6.70
8-22	6.71b	7.10b	6.78	6.80b	6.64	6.77b	6.68	6.47b	6.57	7.65	7.11	7.54	7.47	7.15	6.62	6.88
8-27	6.49	6.71	6.93	6.98	6.74	6.81	6.78	6.78	6.57	7.03	7.09	7.20	7.19	7.21	6.72	6.97
8-30	6.65	7.01b	6.90	6.87b	6.78	6.83b	6.81	6.60b	6.48	7.08	7.28	7.57	7.53	6.96	6.44	6.90
9-3	6.40	6.71	6.78	6.80	6.80	6.65	6.68	6.42	6.48	-	-	7.03	6.96	7.00	6.63	6.90
9-6	6.41b	6.60b	6.19	6.12	6.28	6.30b	6.26	6.20b	6.05b	7.26	7.46	6.95	7.03	6.41	6.11	6.35

a Indicates pump was shut off the previous day
b Indicates pump was on while taking reading
- Reading not taken

TABLE H-6. RESULTS OF GROUNDWATER AMMONIA-NITROGEN MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	11	12	13	14	M1	M2	CC
5-25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
6-10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	8.0	10	50	125	125	<1.0	<1.5	<1.0
6-12	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	15	250	75	100	62	<1.0	<1.0	<1.0
6-14	2.5	2.5	6.0	2.5	1.5	8.0	5.0	2.5	20	150	125	125	125	<1.0	<1.0	<1.0
6-17	<1.0	<1.0	2.5a	<1.0	1.5	<1.0	1.5	2.5	35	162	225	125	175	<1.0	<1.0	<1.0
6-19	<1.0	<1.0	2.5a	<1.0	<1.0a	<1.0	<1.0a	4.5	62	250	250	250	250	<1.0	<1.0	<1.0
6-20	<1.0	<1.0a	12.5	<1.0a	<1.0	<1.0a	<1.0	2.5a	62	250	250	450	450	<1.0	<1.0	<1.0
6-26	4.0	<1.0	2.5	<1.0	<1.0	<1.0	<1.0	2.5	112	400	250	400	250	<1.0	<1.0	<1.0
6-28	4.5	ND	2.0	<1.0	<1.0	<1.0	<1.0	2.5	100	3000	4500	2500	3000	ND	ND	ND
7-1 b	1.5	ND	<1.0	ND	ND	ND	<1.0	2.5	10	<1.0	<1.0	200	100	<1.0	<1.0	<1.0
7-5	1.0	<1.0	<1.0	ND	ND	ND	ND	3.0	80	800	1500	1500	500	<1.0	1.0	-
7-9	1.0	<1.0	<1.0	ND	ND	ND	<1.0	4.0	60	2500	c	2500	2500	<1.0	<1.0	-
7-12	1.0	ND	<1.0	ND	ND	ND	<1.0	2.0	100	1500	1500	1500	c	ND	ND	-
7-15	1.0	ND	7.0	ND	<1.0	ND	1.0	7.0	90	-	-	-	-	ND	ND	-
7-17	<1.0	ND	4.0	ND	1.5	ND	<1.0	4.5	80	-	-	-	-	-	-	-
7-19	4.0	ND	3.0	ND	1.0	ND	<1.0	0.0	60	2000	2000	2000	2000	ND	ND	<1.0
7-23	1.0	ND	2.0	ND	1.0	ND	ND	4.0	80	-	-	-	-	-	-	-
7-25	2.0	1.0	2.0	ND	1.0	ND	<1.0	5.0	60	2000	2000	2000	2000	<1.0	<1.0	-
7-30	1.0	ND	3.0	ND	<1.0	ND	<1.0	4.0	60	2000	2000	2000	2000	ND	ND	-
8-6	2.0	1.0	2.0	ND	2.0	ND	<1.0	5.0	60	2000	2000	2000	2000	ND	ND	-
8-9	2.5	<1.0	1.0	ND	1.0	ND	<1.0	6.0	80	1500	2225	2225	2500	-	<1.0	-
8-14	3.5	2.0	1.0	ND	5.5	<1.0	2.0	2.0	90	-	-	-	-	-	-	-
8-16	4.5	2.0	<1.0	ND	5.0	1.0	<1.0	12.0	50	2000	2000	2000	2000	<1.0	<1.0	<1.0
8-19	5.0	1.5	1.0	ND	20.0	1.0	1.0	16.0	80	-	-	-	-	-	-	-
8-21	4.5	1.5	<1.0	ND	28.0	<1.0	<1.0	10.0	80	-	-	-	-	-	-	-
8-24	8.0	2.5	1.0	ND	27.0	1.0	1.0	10.0	60	2000	2250	2000	2000	ND	<1.0	<1.0
8-27	7.5	2.0	<1.0	ND	20.0	1.0	1.0	12.5	80	-	-	-	-	-	-	-
8-30	5.0	1.0	<1.0	ND	20.0	2.0	1.0	10.0	60	2000	1000	2000	1000	ND	1.0	-
9-3	5.0	2.5	<1.0	<1.0	15.0	2.0	1.0	12.5	80	-	-	-	-	-	-	-

NH_3 readings in mg/1

-	Indicates reading not taken
ND	None detected
a	Indicates pump was off the previous day
b	After 2 days of no Restore® 375K addition
c	Indicates pump out of service

Nutrient addition started 06-07-85
H_2O_2 addition started 06-26-85

TABLE H-7. RESULTS OF GROUNDWATER PHOSPHATE MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
6-10	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	10	37	175	125	<0.5	<0.5	<0.5
6-12	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	87	125	100	87	<0.5	<0.5	<0.5
6-14	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8	150	175	175	175	<0.5	<0.5	<0.5
6-17	<0.5	<0.5	<0.5a	<0.5	<0.5	<0.5	<0.5	<0.5	2.5	175	175	175	175	<0.5	<0.5	<0.5
6-19	<0.5	<0.5	<0.5a	<0.5	<0.5a	<0.5	<0.5a	<0.5	3.5a	350	250	350	250	<0.5	<0.5	<0.5
6-20	<0.5	<0.5a	<0.5	<0.5a	<0.5	<0.5a	<0.5	<0.5a	4	350	250	350	350	<0.5	<0.5	<0.5
6-26	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.0	60	500	300	500	350	1.0	<0.5	1.0
6-28	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	50	600	400	800	800	0.5	<0.5	0.5
7-1b	<0.5	ND	ND	ND	ND	ND	ND	ND	50	ND	<0.5	350	300	10	<0.5	0.5
7-5	ND	ND	ND	ND	ND	ND	ND	ND	40	2000	2000	2500	600	<0.5	<0.5	-
7-9	ND	ND	ND	ND	ND	ND	ND	ND	30	4000	c	4000	4000	10	<0.5	-
7-12	ND	ND	ND	ND	ND	ND	ND	ND	35	3000	3000	3000	c	<0.5	-	-
7-15	ND	ND	ND	ND	ND	ND	ND	1.0	60	-	-	-	-	<0.5	ND	-
7-17	ND	ND	ND	ND	ND	ND	ND	0.5	60	-	-	-	-	-	-	-
7-19	ND	ND	ND	ND	ND	ND	ND	0.5	60	2500	2500	2500	2500	<0.5	0.5	-
7-23	ND	ND	ND	ND	ND	ND	[illegible]	0.5	40	-	-	-	-	-	-	ND
7-25	ND	ND	ND	ND	ND	ND	ND	<1.0	30	2500	2500	2500	2500	1.0	<1.0	-
7-30	ND	ND	ND	ND	ND	ND	ND	6.0	40	2000	2000	2000	2500	ND	ND	-
8-6	ND	ND	ND	ND	ND	ND	ND	6.0	20	5000	5000	5000	5000	<0.5	<0.5	-
8-9	ND	ND	ND	ND	ND	ND	ND	8.0	60	1750	1750	2000	2000	0.5	ND	-
8-14	ND	ND	ND	ND	ND	ND	ND	10.0	50	-	-	-	-	-	-	-
8-16	ND	ND	ND	ND	<0.5	ND	ND	10.0	60	5000	5000	5000	5000	2.0	ND	<0.5
8-19	0.5	ND	ND	ND	0.5	ND	ND	12.0	50	-	-	-	-	-	-	-
8-21	ND	ND	ND	ND	1.0	<0.5	ND	6.0	60	-	-	-	-	-	-	-
8-24	ND	ND	ND	ND	1.0	ND	ND	10.0	40	3000	3500	3000	3000	ND	ND	ND
8-27	ND	ND	ND	ND	0.5	ND	ND	10.0	60	-	-	-	-	-	-	-
8-30	ND	ND	ND	<0.5	<0.5	ND	ND	7.0	40	5000	4000	4000	4000	ND	ND	-
9-3	ND	ND	ND	ND	<0.5	ND	ND	6.0	60	-	-	-	-	-	-	-

PO_4 readings in mg/l

-	Indicates reading not taken
ND	None detected
a	Indicates pump was off the previous day
b	After 2 days of no Restore® 375K addition
c	Indicates pump out of service

Nutrient addition started 06-07-85
H_2O_2 addition started 06-26-85

TABLE H-8. RESULTS OF GROUNDWATER CHLORIDE MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
6-5	68	44	40	28	32	30	36	40	48	40	36	40	56	24	32	-
6-10	80	33	38	25	35	26	70	70	200	120	250	400	350	12	25	25
6-12	75	31	135	21	70	24	79	95	225	125	250	450	300	12	26	25
6-14	77	35	360	22	270	200	150	150	450	1000	1250	1300	1350	12	25	25
6-17	88	37	180a	23	300	210	145	155	650	1150	1750	1500	1500	15	30	26
6-19	105	38	325a	28	320a	125	150a	275	850a	1950	2600	3800	2500	12	38	25
6-20	106	40a	525	26a	300	110a	125	200a	820	3000	3100	3100	3400	13	30	25
6-26	205	41	120	28	260	120	175	155	800	3000	3100	1700	1300	15	30	24
6-28	225	45	150	27	50	32	75	51	280	8500	2000	8000	6000	15	33	22
7-1b	110	70	70	31	55	29	79	53	555	1300	1600	1500	1500	25	42	25
7-5	205	82	65	30	48	75	70	75	-	3600	4000	6500	1500	24	70	-
7-9	250	90	55	31	42	46	90	55	310	5600	c	6500	5500	20	53	-
7-12	220	85	47	27	43	44	73	45	700	75	70	82	c	23	50	-
7-15	255	155	60	31	110	39	70	100	1500	-	-	-	-	30	53	-
7-17	260	150	290	50	180	52	112	100	1050	-	-	-	-	-	-	-
7-19	275	235	275	125	195	115	140	125	700	5500	5500	5500	5500	20	30	-
7-23	350	230	125	40	165	45	70	52	800	-	-	-	-	-	-	-
7-25	-	350	200	110	220	130	150	160	640	5000	5000	5000	5000	110	200	100
7-30	305	235	250	95	160	125	155	115	750	5000	5000	5000	5000	20	30	20
8-6	275	245	285	150	205	125	150	125	750	500	500	500	500	20	30	20
8-9	675	425	165	55	165	75	135	170	900	550	420	600	570	75	275	-
8-14	875	650	150	100	475	245	275	350	700	-	-	-	-	-	-	-
8-16	925	650	160	100	550	225	275	185	765	5500	6200	5200	6300	75	375	100
8-19	1100	705	185	120	825	165	205	160	980	-	-	-	-	-	-	-
8-21	1150	685	200	115	550	225	180	125	1000	-	-	-	-	-	-	-
8-24	1650	850	290	200	750	330	270	250	1030	1500	7500	1600	1800	150	400	180
8-27	1000	700	230	150	560	230	200	200	1000	-	-	-	-	-	-	-
8-30	1220	770	200	120	550	230	160	150	810	800	300	360	340	100	470	-
9-3	1100	750	200	130	600	250	190	190	830	-	-	-	-	-	-	-

Cl readings in mg/l

-	Indicates reading not taken
a	Indicates pump was shut off the previous day
b	After 2 days of no Restore® 375K addition
c	Indicates pump out of service

Nutrient addition started 06-07-85
H_2O_2 addition started 06-26-85

TABLE H-9. RESULTS OF GROUNDWATER HYDROGEN PEROXIDE MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
6-4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	-
6-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-28	ND	ND	ND	ND	ND	ND	ND	ND	ND	15000	7000	5000	10000	ND	ND	ND
7-1a	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	500	500	500	ND	ND	ND
7-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	300	500	300	500	ND	ND	-
7-9b	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	c	ND	ND	ND	ND	-
7-12b	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	c	ND	ND	-
7-15	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	ND	ND	-
7-17	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-	ND
7-19	ND	ND	ND	ND	ND	ND	ND	ND	ND	8000	8000	8000	8000	ND	ND	ND
7-23	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-	ND
7-25	ND	ND	ND	ND	ND	ND	ND	ND	ND	10000	10000	10000	10000	ND	ND	-
7-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	5000	5000	5000	5000	ND	ND	-
8-6	-	-	-	-	-	-	-	-	-	-	-	-	-	ND	ND	-
8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	ND	ND	-
8-16	ND	ND	ND	ND	ND	ND	ND	ND	ND	160	140	130	160	ND	ND	ND
8-19	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-	-
8-21	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-	-
8-24	ND	ND	ND	ND	ND	ND	ND	ND	ND	400	240	320	400	ND	ND	ND
8-27	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	ND	-	-	-
8-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	500	500	500	500	ND	ND	-
9-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-	-

H_2O_2 readings in mg/l

- Indicates reading not taken
ND None detected

a After 2 days of no Restore® 375K addition
b Alternate H_2O_2 test was used
c Indicates pump out of service

Nutrient addition started 06-07-85
H_2O_2 addition started 06-25-85

TABLE H-10. RESULTS OF GROUNDWATER ALKALINITY MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-27	424	456	396	384	380	376	412	440	456	432	376	320	384	288	452	-
6-12	408	500	500	430	540	520	520	600	520	580	580	600	520	500	600	580
6-20	580	420	460	480	500	500	540	580	500	680	580	620	520	400	560	580
7-5	415	420	400	340	350	384	370	292	410	4000	5000	3600	3600	290	430	-
7-27	-	-	-	-	-	-	-	-	-	1050	1150	1040	1100	-	-	-
8-3	-	-	-	-	-	-	-	-	-	1100	1050	1030	1050	-	-	-
9-8	272	224	320	340	344	328	376	346	470	364	372	388	372	284	354	360

Alkalinity readings in mg/l
- Indicates reading not taken
Nutrient addition started 06-07-85

TABLE H-11. RESULTS OF GROUNDWATER ACIDITY MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
6-4	68	44	48	44	48	60	52	52	56	48	28	56	52	32	92	-
6-12	64	10	44	40	28	44	165	120	60	140	200	260	300	120	220	160
6-20	80	20	100	184	140	62	88	124	104	224	260	260	220	52	108	92
7-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7-27	-	-	-	-	-	-	-	-	-	240	250	230	240	-	-	-
8-3	-	-	-	-	-	-	-	-	-	250	250	232	250	-	-	-
9-8	78	56	88	112	116	96	94	96	256	72	68	186	134	64	142	124

Acidity readings in mg/l
- Indicates reading not taken
Nutrient addition started 06-07-85

TABLE H-12. RESULTS OF GROUNDWATER HARDNESS MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-28	276	264	280	296	308	312	292	260	276	260	248	256	272	236	204	-
6-12	454	454	412	330	452	412	412	412	536	330	330	240	330	330	412	-
6-20	432	30	400	332	400	336	372	380	464	-	-	-	-	-	-	-
7-27	-	-	-	-	-	-	-	-	-	1120	1250	1210	1210	-	-	-
8-3	-	-	-	-	-	-	-	-	-	1150	1210	1160	1230	-	-	-
9-11	1600	1032	464	877	671	361	413	413	722	516	516	310	361	310	800	361

Hardness readings in mg/l
- Indicates reading not taken
Nutrient addition started 06-07-85

TABLE H-13. RESULTS OF GROUNDWATER NITRATE-NITROGEN MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-28	4.4	4.4	4.4	22.0	ND	4.4	4.4	ND	4.4	6.6	4.4	ND	4.4	17.6	8.8	-
6-12	<4.4	<4.4	4.4	17.6	35.2	<4.4	<4.4	<4.4	8.8	6.6	6.6	4.4	8.8	<4.4	17.6	8.8
6-20	<4.4	<4.4	<4.4	4.4	13.2	<4.4	<4.4	<4.4	13.2	4.4	6.6	6.6	13.2	<4.4	13.2	-
7-5	ND	ND	13.2	30.8	13.2	13.2	ND	ND	<4.4	<4.4	ND	<4.4	ND	<4.4	17.6	-
7-19	ND	ND	13.2	70.4	13.2	ND	ND	ND	ND	ND	ND	<4.4	<4.4	13.2	13.2	-
7-27	ND	ND	11.0	8.8	6.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.8	<4.4
8-3	ND	ND	11.0	11.0	8.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.6	<4.4
8-16	4.4	ND	13.2	141.0	13.2	ND	ND	ND	ND	<4.4	<4.4	<4.4	<4.4	<4.4	8.8	8.8
8-24	6.6	ND	79.2	35.2	8.8	ND	ND	ND	ND	4.4	4.4	<4.4	4.4	ND	8.8	8.8
9-6	13.2	ND	ND	26.4	ND	ND	ND	ND	4.4	ND	ND	ND	ND	ND	6.6	6.6
9-12	8.8	ND	8.8	44.0	8.8	ND	ND	ND	<4.4	ND	ND	ND	ND	-	-	-

NO_3 readings in mg/1
- Indicates reading not taken
ND None detected
Nutrient addition started 06-07-85

TABLE H-14. RESULTS OF GROUNDWATER SULFATE MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-27	20	65	50	50	65	20	20	50	20	50	50	50	20	35	65	-
6-12	35	80	10	65	50	50	65	10	50	10	10	10	10	35	35	-
6-20	35	100	100	80	65	50	50	50	50	10	10	10	10	35	65	35
7-5	30	100	80	100	120	120	ND	20	50	20	20	20	ND	60	ND	35
7-19	50	80	80	60	80	60	ND	20	20	200	200	200	200	20	20	-
7-27	20	80	50	20	50	20	50	50	20	20	20	20	ND	20	20	20
8-3	20	80	50	20	50	50	50	50	ND	20	20	20	ND	20	20	20
9-11	30	70	60	40	90	30	20	40	50	40	60	ND	ND	30	140	60
9-12	30	70	70	60	120	60	60	30	80	10	>200	ND	ND	-	-	-

SO_4 readings in mg/l
- Indicates reading not taken
ND None detected
Nutrient addition started 06-07-85

TABLE H-15. RESULTS OF GROUNDWATER LEAD MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2	CC
5-28	0.1	ND	0.1	ND	0.1	0.05	0.1	ND	0.05	0.1	0.05	0.1	0.1	ND	ND	-
7-5	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
7-27	0.8	0.1	<0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
8-3	0.8	0.1	<0.1	ND	ND	ND	ND	ND	ND	-	-	-	-	ND	ND	ND
9-11	0.15	ND	ND	0.15	0.15	0.05	0.05	ND	ND	-	-	-	-	0.05	0.05	0.05

Pb readings in mg/l
- Indicates reading not taken
ND None detected

TABLE H-16. RESULTS OF GROUNDWATER CHROMIUM MONITORING

Date	P1	P2	P3	P4	P5	P6	P7	P8	P9	I1	I2	I3	I4	M1	M2
6-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3 0.3
6-12	ND ND	ND ND	ND ND	0.15 0.15	<0.1 <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	0.3 0.3
6-20	ND <0.1	ND <0.1	ND <0.1	0.15 0.15	<0.1 <0.1	ND <0.1	ND <0.1	ND <0.1	ND <0.1	- -	- -	- -	- -	- -	- -
7-27	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	ND	ND
8-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	ND	ND
9-6	- ND	- ND	- ND	- <0.1	- ND	- ND	- ND	- ND	- ND	- -	- -	- -	- -	- ND	- ND

Cr readings in mg/l; $\frac{\text{Total Cr}}{Cr^{+6}}$

- Indicates reading not taken
ND None detected

TABLE H-17. GROUNDWATER TOTAL MICROBIAL POPULATIONS[a]

Date: Days Well #	05-15[b] 0	06-06[c] 22	06-25[d] 41	07-15 61	07-31 77	08-14 91	08-29 106
P-1	5.7	2.4		21	4.1	2	8
P-2	11	7.6	0.95	7.8	3.4	0.85	20
P-3	28	1	0.68	22	1.7	2.7	6.8
P-4	24		0.99	4.4	0.19	3.4	2.8
P-5	15	31	2.4	8.3	0.083	1.7	5.2
P-6	15	2.9	0.97	8.9	0.52	2.1	2.8
P-6R							24
P-7	29	2.3	2.9	3.8	1.2	3	15
P-8	4.3	1.5	0.6	11	0.95	3.2	3
P-9	0.4	9	3.2	20	0.74	1.9	3.1
P-9R							0.25
I-1	5.8			100	0.04	0.001	0.001
I-2	0.7			5	0.017	0.001	0.001
I-3	3.9			1.8	0.39	0.001	0.001
I-4	4.4			32	0.76	0.001	0.001
M-1	17	0.4	38	22	14	25	16
M-2	1.9	1	1.3	11	1.3	22	15

[a] cells/ml x 1 x E5.

[b] Before circulation was initiated.

[c] One day prior to nutrient start-up.

[d] Two weeks after nutrient start-up and 3 days before H_2O_2 start-up.

Note: Limit of detection is 0.001 x E5.

TABLE H-18. GROUNDWATER HYDROCARBON-DEGRADING MICROBIAL POPULATIONS[a]

Date:	05-15[b]	06-06[c]	06-25[d]	07-15	07-31	08-14	08-29
Days	0	22	41	61	77	91	106
Well #							
P-1	0.4	1.3		1.4	0.013	0.4	0.42
P-2	2.6	0.3	0.095	0.12	0.06	0.12	0.79
P-3	3.9	0.03	0.16	8.8	0.006	1.5	1
P-4	3.9	0.5	0.031	1.4	0.048	1.3	0.42
P-5	2.5	0.1	0.037	0.015	0.005	1.4	0.38
P-6	7.3	0.6	0.12	1.5	0.11	0.37	0.76
P-6R							2.3
P-7	8.7	0.7	0.002	0.078	0.067	2.1	2.2
P-8	1.8	0.04	0.004	1	0.25	1.8	0.2
P-9	0.07	1.1	0.079	11	0.05	0.63	0.57
P-9R							0.01
I-1	1.9			130	0.001	0.001	0.001
I-2	1.3	0.8		2.8	0.001	0.001	0.001
I-3	0.7			3.7	0.02	0.001	0.001
I-4	1.2			7	0.34	0.001	0.001
M-1	4.9	0.2	0.8	2.9	2.5	0.68	1.4
M-2	0.2	0.7	0.34	2	0.87	11	16

[a] cells/ml x 1 x E5.

[b] Before circulation was initiated.

[c] One day prior to nutrient start-up.

[d] Two weeks after nutrient start-up and 3 days before H_2O_2 start-up.

Note: Limit of detection is 0.001 x E5.

TABLE H-19. SOIL MICROBIAL POPULATIONS[a]

Soil Boring	Depth (feet)	Total Bacteria (cells/gm)	Hydrocarbon Degrading Bacteria (cells/gm)
P-1	22	1.0×10^7	1.1×10^7
P-1	27	7.8×10^6	5.1×10^6
P-3	21	3.4×10^6	1.9×10^6
P-3	28	1.1×10^5	6.4×10^4
I-2	20	4.3×10^4	1.8×10^4
I-2	28	1.1×10^5	1.1×10^5
I-3	25	8.3×10^4	6.0×10^4
I-3	30	1.9×10^6	1.6×10^6

[a] Samples collected during wel construction, 22 April - 30 April 1985.

TABLE H-20. SOIL MICROBIAL POPULATIONS[a]

Soil Boring[b]	Depth (feet)	Total Bacteria (cells/gm)	Hydrocarbon Degrading Bacteria (cells/gm)
I-2	25-27	1.0×10^6	2.4×10^5
I-3	25-27	1.2×10^7	5.3×10^5
I-3	25-27	6.9×10^6	1.4×10^6
I-4	25-27	3.7×10^6	1.2×10^5
I-4	25-27	1.4×10^7	8.5×10^5
P-9	25-27	2.9×10^6	8.5×10^5
P-9	25-27	4.0×10^4	1.2×10^4

[a] Samples collected 30 July - 03 August 1985.

[b] Duplicate microbial counts were performed; samples were taken from location nearest well indicated, at specified depth.

TABLE H-21. WATER LEVEL SUMMARY[a]

Date / Well	5-17	5-23	5-30	6-4			6-5		6-6	6-7		6-8	6-10	6-11						6-15
				0900	1200	1730	0830	1700	0830	0800	1400	0830	0900	1000	1200	1700	0800	1500	1600	
P1	21.1	20.9	21.1	-	-	-	-	-	-	18.6	-	-	20.8	-	-	21.0	23.0	21.2	21.2	-
P2	21.4	21.4	21.4	-	-	-	-	-	-	23.1	23.3	-	21.4	-	-	27.4	22.0	21.6	21.7	-
P3	21.3	21.1	21.4	-	-	-	-	-	-	20.5	-	-	22.7	-	-	21.3	21.5	21.4	21.5	-
P4	21.2	20.9	21.2	-	-	-	-	-	-	18.1	-	-	-	-	-	21.2	21.4	21.2	21.4	-
P5	20.3	21.0	21.3	-	-	-	-	-	-	18.8	-	-	-	-	-	20.8	21.3	21.6	21.5	-
P6	20.9	20.6	21.0	-	-	-	-	-	-	18.1	-	-	-	-	-	20.9	21.2	20.9	21.1	-
P7	20.6	20.4	20.7	-	-	-	-	-	-	19.0	-	-	20.1	-	-	21.4	21.4	20.8	21.1	-
P8	20.1	19.9	20.1	-	-	-	-	-	-	17.7	-	-	18.8	-	-	19.8	20.0	20.1	20.2	-
P9	20.8	20.5	20.7	-	-	-	-	-	-	18.3	-	-	24.4	20.2		20.6	20.4	20.7	20.8	-
11	-	20.6	20.8	18.4	18.9	18.9	19.4	19.4	18.8	17.7	17.7	16.7	17.4	8.0	5.9	10.0	5.4	+	2.9	+
12	-	21.4	21.1	0.8	10.5	9.8	9.1	+	18.7	+	13.5	17.8	+	8.7	9.7	9.6	9.6	10.2	3.4	-
13	-	20.8	21.1	9.8	12.7	13.8	16.1	13.7	10.4	10.7	9.1	3.9	7.4	7.4	7.4	5.3	2.3	6.7	3.6	+
14	-	20.2	20.4	18.3	18.9	18.7	19.2	19.2	18.1	17.5	17.5	7.6	+	8.6	11.6	9.5	5.6	+	+	+
M 1	-	23.0	14.8	13.7	-	13.7	14.1	14.2	12.6	12.2	-	-	-	-	-	14.9	15.0	14.8	15.4	-
M 2	-	14.5	23.3	23.5	-	23.1	23.1	23.0	23.0	20.4	-	-	-	-	-	23.3	23.5	23.0	23.8	-
CC	-	-	-	-	-	-	-	-	-		-	-	-	-	-	22.7	22.6	22.7	22.7	-

- no reading taken
+ level at or near ground surface
a readings in feet below ground surface

TABLE H-21. WATER LEVEL SUMMARY (Continued)

Date / Well	6-16	6-17		6-18		6-19		6-20		6-21		6-22	6-23	6-24		6-25	6-26		6-27	6-28
		0900	1600	0900	1600	0900	0700	0900		0900	1800			0900	1700		0800	1700	0900	1230
P1	-	26.3	-	27.3	24.1	-	26.5	25.0	-	25.8	-	-	-	-	24.6	18.6	19.9	-	22.1	20.7
P2	-	26.4	-	25.1	24.5	-	22.7	22.4	-	23.1	-	-	-	-	20.2	20.5	20.2	-	24.3	20.9
P3	-	21.6	-	22.0	22.2	-	23.6	21.8	-	21.6	-	-	-	-	20.0	21.2	20.2	-	24.7	21.0
P4	-	22.1	22.3	22.6	22.4	-	22.0	21.7	-	21.2	-	-	-	-	18.5	19.1	20.0	-	20.6	20.8
P5	-	22.3	22.2	22.5	22.2	-	22.3	21.9	-	21.7	-	-	-	-	19.2	19.5	20.0	-	20.7	20.8
P6	-	23.0	22.9	23.1	23.0	-	21.6	21.4	-	21.1	-	-	-	-	18.6	18.9	20.9	-	21.5	20.4
P7	-	25.8	25.2	22.9	21.5	-	23.7	21.4	-	21.2	-	-	-	-	19.9	19.9	20.6	-	22.3	20.3
P8	-	21.0	-	21.1	21.0	-	20.9	20.7	-	20.2	-	-	-	-	19.7	18.7	19.2	-	19.7	19.8
P9	-	21.7	21.6	21.5	21.5	-	21.5	21.2	-	20.9	-	-	-	-	19.2	19.3	19.7	-	20.3	20.4
11	+	12.8	10.9	6.7	2.3	12.2	9.7	-	17.8	20.3	15.5	+	+	5.2	-	15.1	4.0	4.9	+	+
12	+	18.4	13.6	10.6	9.6	5.6	4.5	5.2	9.4	18.6	18.0	+	+	14.3	13.9	14.8	6.3	6.2	+	+
13	+	7.7	3.8	+	+	14.0	12.6	8.4	12.9	15.1	10.7	+	+	+	4.2	12.9	+	+	+	+
14	+	2.1	+	+	+	+	4.6	1.5	9.5	12.9	11.9	-	-	+	+	11.4	3.4	2.9	+	+
M 1	-	15.7	16.7	16.1	16.3	14.3	14.3	13.9	14.1	13.7	13.9	-	-	13.3	13.2	13.7	14.0	-	15.0	15.1
M 2	-	22.9	22.9	23.8	23.9	23.9	23.9	23.8	23.4	23.1	23.6	-	-	22.4	22.5	22.4	22.8	-	22.9	23.1
CC	-	23.0	22.9	23.2	23.0	23.0	23.1	23.1	23.1	23.1	22.9	-	-	21.8	21.8	21.9	21.9	-	22.1	22.3

- no reading taken
+ level at or near ground surface

TABLE H-21. WATER LEVEL SUMMARY (Continued)

Date / Well	6-28	6-29			6-30	7-1			7-2	7-3	7-4	7-5	7-6	7-7	7-8	7-9	7-10	7-11	7-12	
	1500	1200	1430	1830	0800	0900	1730	1900	1430		1500	1000			1000	0930	1030	0945	0900	1530
P1	-	20.8	-	-	21.1	20.7	-	-	21.2	BAD WEATHER	19.7	19.1	SYSTEM DOWN	SYSTEM DOWN	20.3	20.5	20.6	20.6	20.6	-
P2	-	20.8	-	-	20.8	23.1	-	-	21.4		20.1	19.1			20.6	20.8	20.8	20.8	21.0	-
P3	-	21.1	-	-	21.2	21.4	-	-	20.9		19.8	19.3			20.5	20.9	21.0	21.1	21.2	-
P4	-	20.9	-	-	21.1	21.3	-	-	21.4		19.2	18.8			20.4	20.8	20.8	20.7	20.8	-
P5	-	21.0	-	-	21.1	21.4	-	-	21.4		19.5	19.0			20.5	20.7	21.0	21.8	20.9	-
P6	-	20.5	-	-	20.6	21.1	-	-	20.9		19.6	18.8			20.1	20.5	20.3	20.7	20.5	-
P7	-	20.4	-	-	20.4	20.7	-	-	20.7		19.4	18.8			19.9	20.1	20.2	20.3	20.3	-
P8	-	20.0	-	-	20.1	20.3	-	-	20.3		19.1	18.6			19.7	20.0	20.0	19.9	19.9	-
P9	-	20.5	-	-	20.7	20.9	-	-	21.0		19.6	19.2			20.2	20.4	20.4	20.5	20.4	-
11	+	4.1	+	+	+	+	1.5	+	3.9		14.4	17.9			20.2	20.5	20.8	20.7	21.9	7.9
12	+	4.6	3.3	+	1.0	+	2.9	+	4.7		3.8	2.7			10.3	3.8	19.2	21.2	21.5	5.7
13	+	9.5	+	+	+	+	3.4	+	5.2		8.9	7.7			13.7	15.1	11.9	14.0	14.3	2.9
14	+	9.4	-	6.6		+	3.1	+	4.9		8.6	7.4			13.4	14.8	11.6	13.7	20.2	12.6
M 1	-	15.5	-	-	15.5	15.6	-	-	15.7		12.7	13.6			14.9	15.0	14.9	14.4	14.8	-
M 2	-	23.0	-	-	23.0	23.3	-	-	23.4		22.9	22.8			23.0	23.1	23.1	23.1	23.2	-
CC	-	22.3	-	-	22.3	22.5	-	-	22.6		22.0	21.9			22.2	22.1	22.3	22.4	22.4	-

- no reading taken
+ level at or near ground surface

TABLE H-21. WATER LEVEL SUMMARY (Continued)

Date / Well	7-13	7-14	7-15	7-16	7-17	7-18			7-19			7-20	7-21	7-22	7-23	7-24	7-25	7-26		7-27
	0930		1230	1030	1000	1000	1200	1630	0930	1230	1630	1115	1330	1100	1000	1030	1330	1025	1300	1400
P1	20.9	-	21.1	27.8	21.5	26.7	-	-	21.4	-	-	25.1	21.5	26.1	21.6	21.7	21.9	22.7	-	22.6
P2	21.2	-	21.3	21.4	21.6	26.3	-	-	22.1	-	-	20.9	20.9	24.2	20.9	25.2	22.6	23.5	-	22.0
P3	21.1	-	21.5	21.0	21.6	21.8	-	-	21.6	-	-	21.7	21.8	21.9	22.1	22.1	22.1	22.5	-	22.4
P4	21.2	-	21.3	21.4	21.6	22.3	-	-	21.3	-	-	21.5	21.7	21.6	21.9	22.0	22.1	22.2	-	22.0
P5	21.0	-	21.5	21.7	21.8	22.0	-	-	21.8	-	-	21.5	21.8	22.0	22.0	22.1	22.1	22.8	-	22.7
P6	20.7	-	21.0	21.2	21.2	23.0	-	-	21.1	-	-	21.1	21.3	21.5	21.3	21.6	21.8	21.9	-	21.9
P7	20.4	-	20.8	21.0	21.0	21.3	-	-	21.1	-	-	21.0	21.2	21.3	21.3	21.4	21.6	22.1	-	22.2
P8	20.0	-	20.2	20.5	20.5	20.8	-	-	20.7	-	-	20.6	20.7	20.8	20.8	21.0	21.1	21.5	-	21.5
P9	20.7	-	20.9	21.1	21.1	21.4	-	-	21.1	+	+	21.2	21.2	21.3	21.5	21.5	21.6	21.9	-	21.9
11	20.9	-	21.4	+	15.2	+	4.1	6.7	13.7	+	+	4.9	9.1	+	5.7	4.7	8.8	18.8	+	18.7
12	15.0	-	10.7	+	10.9	+	0.9	2.7	9.2	-	-	2.5	6.0	+	5.3	3.6	8.2	4.7	+	11.8
13	14.3	-	13.5	1.9	13.2	+	6.7	9.5	13.1	-	-	+	12.5	10.2	12.9	9.9	14.0	13.7	-	17.2
14	21.4	-	20.6	6.6	21.1	+	7.4	14.2	20.1	-	-	+	17.0	11.3	21.4	+	14.6	21.7	-	18.1
M 1	15.3	-	15.9	15.3	16.0	16.3	-	-	15.7	-	-	15.5	15.8	16.1	16.4	16.5	16.6	17.0	-	16.1
M 2	23.3	-	22.5	23.4	23.5	23.5	-	-	23.8	-	-	23.8	23.8	23.9	23.9	23.0	23.9	24.2	-	24.2
CC	22.5	-	22.6	22.7	22.7	22.9	-	-	22.9	-	-	22.9	22.9	22.9	22.9	23.7	22.9	23.2	-	23.2

- no reading taken
+ level at or near ground surface

TABLE H-21. WATER LEVEL SUMMARY (Continued)

Date / Well	7-27 2030	7-28 1400	7-29 0830	7-30 0700	7-31 0730	8-1 0830	8-2 0800	8-3 0900	8-4 1000	8-5 1000	8-6 1400	8-7 1310	8-8 1100	8-9 1230	8-10 1430	8-11 0930	8-12 0900	8-13 1030	8-14 0930
P1	-	23.7	23.3	24.4	22.4	23.1	22.1	22.1	22.2	22.3	22.3	22.3	22.6	22.5	22.5	22.6	22.7	28.9	28.9
P2	-	21.9	23.6	21.9	21.9	23.6	22.2	22.2	22.5	22.6	22.5	22.5	22.5	22.5	22.6	22.7	22.8	22.8	26.7
P3	-	22.4	22.6	21.6	21.7	22.9	22.6	22.5	22.5	22.5	22.6	22.5	22.7	22.6	22.6	22.9	22.9	25.0	23.0
P4	-	22.2	22.4	23.2	23.1	21.2	22.1	22.0	22.4	22.3	22.2	22.3	22.6	21.5	22.5	22.7	22.8	22.8	22.8
P5	-	22.7	22.6	21.7	21.6	23.2	22.0	22.1	22.3	22.4	22.6	22.5	22.6	22.6	22.5	22.8	22.8	23.2	23.0
P6	-	21.7	22.1	22.8	22.8	22.4	22.1	22.1	21.8	22.0	22.3	22.2	22.4	22.3	22.2	22.5	22.5	22.5	22.5
P7	-	22.0	22.0	22.7	22.7	22.3	21.7	21.7	22.2	21.9	21.9	21.9	22.0	22.0	22.3	22.3	25.4	25.4	22.4
P8	-	21.4	21.5	22.6	22.6	22.5	21.3	21.2	21.5	21.4	21.4	21.4	21.4	21.4	21.4	21.7	21.7	21.9	21.9
P9	-	21.9	21.9	22.3	22.3	23.0	21.8	21.7	22.0	21.9	22.1	22.0	22.0	22.0	22.0	22.2	22.2	22.6	22.4
11	+	18.7	19.8	21.7	21.7	13.0	17.9	18.8	11.0	16.3	21.0	20.9	9.3	11.9	+	7.5	11.4	6.6	11.6
12	+	4.6	3.3	9.4	9.4	13.6	12.2	11.8	13.2	12.6	9.2	9.1	6.7	6.9	+	9.4	10.0	5.3	9.3
13	+	13.7	13.9	13.0	13.0	16.4	17.3	17.2	16.9	16.9	19.4	19.6	13.9	12.8	7.9	9.5	15.4	6.5	8.2
14	-	21.7	21.7	21.6	21.7	22.1	17.9	18.0	18.5	22.0	21.7	21.6	20.8	13.4	8.9	7.5	18.8	3.3	1.8
M 1	-	17.0	17.0	17.3	17.3	17.3	16.1	16.1	16.4	16.4	16.6	16.6	16.8	16.9	17.0	17.3	17.3	17.3	17.5
M 2	-	24.2	24.2	24.2	24.2	24.4	24.2	24.2	24.7	24.7	24.0	24.0	24.2	24.3	24.3	24.2	24.2	24.2	24.3
CC	-	23.2	23.2	23.5	23.5	23.7	24.5	23.6	23.4	23.5	23.3	23.3	23.3	23.4	23.4	24.4	23.4	23.4	23.4

- no reading taken
+ level at or near ground surface

TABLE H-21. WATER LEVEL SUMMARY (Continued)

Date / Well	8-15 0830	8-16 0900	8-17 0900	8-18 1000	8-19 1130	8-20 1630	8-21 1100	8-22 0930	8-23 1830	8-24 1200	8-25 0900	8-26	8-27 1200	8-28 1000	8-29 1100	8-30 1200	8-31 1000	9-1 0830	9-2 1300	9-3 0900	9-4 1200	9-5 1200	9-6 0930
P1	27.9	22.9	22.9	22.9	22.9	27.9	22.9	27.0	23.2	23.0	22.9	NO READINGS TAKEN SYSTEM DOWN	22.9	22.9	22.9	22.9	22.9	-	22.6	22.7	22.8	22.8	22.9
P2	22.7	22.8	22.8	22.8	22.9	22.8	22.9	26.6	23.2	23.3	22.8		22.9	22.9	22.9	27.3	22.8	-	22.9	22.8	22.8	22.9	22.8
P3	23.0	23.0	23.1	23.1	22.2	23.5	23.2	23.2	-	23.2	29.0		23.0	23.0	23.1	23.0	23.0	-	22.9	23.0	23.1	23.2	23.0
P4	23.0	22.8	22.8	23.0	23.1	23.2	23.0	23.3	-	23.0	22.8		22.9	22.8	22.8	23.0	22.8	-	22.8	22.8	22.9	23.1	22.9
P5	23.0	23.0	23.0	23.1	23.1	23.1	23.0	23.3	23.2	23.4	22.9		23.0	23.0	23.0	23.0	23.0	-	22.9	22.9	23.0	23.0	23.0
P6	22.7	22.5	22.6	22.9	22.8	22.9	22.8	22.9	23.0	22.9	22.8		22.7	22.6	22.6	22.7	22.6	-	22.5	22.6	22.6	23.8	22.6
P7	22.5	22.4	22.5	22.6	22.6	22.8	22.6	22.8	22.8	22.8	22.6		22.5	22.5	22.5	22.4	22.4	-	22.4	22.4	22.7	22.5	22.4
P8	22.0	21.8	22.1	22.1	22.1	22.1	22.1	22.2	22.2	22.2	22.1		22.1	22.1	22.0	21.9	22.0	-	21.8	22.0	22.0	21.9	22.0
P9	22.6	22.5	22.6	22.6	22.6	22.6	22.6	22.7	22.7	22.7	22.6		22.6	22.6	22.6	22.5	21.7	-	22.4	22.5	22.5	22.5	22.6
11	+	7.4	6.5	+	13.4	14.2	19.1	+	6.7	5.5	11.7		12.5	-	-	4.9	8.9	+	7.5	+	22.9	7.1	9.3
12	+	6.7	5.8	1.8	12.1	+	3.9	5.7	11.2	+	10.2		11.8	-	-	+	5.6	+	10.3	+	24.0	10.9	12.3
13	8.7	5.9	+	1.7	-	8.6	9.9	5.3	13.8	+	12.9		15.5	-	-	+	8.3	+	15.8	+	11.9	10.6	11.9
14	+	13.4	+	+	-	+	8.1	+	11.4	+	11.7		15.2	-	-	+	6.5	-	14.3	+	10.1	8.8	11.6
M 1	17.5	17.3	17.4	17.4	17.8	17.9	17.8	17.9	17.3	17.3	17.3		16.0	16.2	16.6	14.9	15.5	-	16.1	16.5	16.5	16.6	15.8
M 2	24.3	24.3	24.3	24.3	24.3	24.3	24.3	23.5	24.3	24.3	24.3		24.3	24.3	24.3	24.2	24.2	-	24.2	24.2	24.4	24.3	24.2
CC	23.4	23.4	23.4	23.4	23.5	23.4	23.5	24.2	23.4	23.4	23.4		23.4	23.4	23.4	23.4	23.4	-	23.3	23.3	23.4	23.3	23.4

- no reading taken
+ level at or near ground surface

TABLE H-22. GROUND SURFACE ELEVATIONS

Well Number	Ground Surface Elevation (ft ASL[a])
P-1	638.53
P-2	638.14
P-3	638.67
P-4	638.64
P-5	638.68
P-6	638.54
P-7	638.08
P-8	637.42
P-9	637.98
I-1	638.17
I-2	638.33
I-3	638.66
I-4	637.83
M-1	637.14
M-2	636.65
CC	635.80

[a] Above sea level

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